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TIME TO EXHAUSTION AT 90 AND 100% VO_2MAX AND PHYSIOLOGICAL DETERMINANTS OF 3 KM PERFORMANCE IN ELITE CYCLISTS

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Abstract:
The minimal power that elicits VO_2max and the time to exhaustion (tlimit) at this workload appear to determine cyclists' endurance capabilities, analyze performance and help coaches to design training. Data in the literature are limited so as to elucidate this. The aim of this study was to investigate the tlimit at the power output, which corresponds to 90 (tlimit 90) and 100% VO_2max (tlimit 100) in elite endurance cyclists. The contribution of tlimit in 3 km indoor individual time trial was also studied. Subjects were eleven elite male road cyclists (age 17.7 ± 0.5 years, body mass 66.8 ± 4.9 kg, body height 176.3 ± 7.4 cm, VO_2max 69.77 ± 2.58 $ml.kg^{-1}.min^{-1}$). Power output at 90 and 100% VO_2max was determined by continuous incremental testing. This protocol had steps of 2 min and increments of 30 W. The exhaustive trials tlimit 90 or tlimit 100 were performed in random order at least five days apart. Five days after the last exhaustive trial, cyclists performed an individual 3 km time trial on an indoor wooden track. Mean ±sd, tlimit 90 and tlimit 100 were 16:27.73 ± 07:46.6 and 4:48.6 ± 00:53.2 min:sec. Time to exhaustion at tlimit 90 and tlimit 100 ranged between 07:00-30:15 and 03:10-06:00 min:sec, respectively. Tlimit 100, tlimit 90 and VO_2max ($ml.min^{-1}$) did not correlate with 3 km cycling

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performance ($r = 0.08$, 0.16 and –0.59, $p > 0.05$). Tlimit 90 was inversely related ($r = –0.49$, $p = 0.1$) with VO_2max ($ml.min^{-1}$). Only power output which corresponded to ventilatory threshold and VO_2max correlated significantly with 3 km performance ($r = –0.83$ and –0.80, $p < 0.01$). The results of this study indicate that: a) if cyclists' training intensity is based on $\%VO_2max$, individual determination of the tlimit at the $\%VO_2max$ has to be considered due to a wide range of tlimit to exhaustion; b) 3 km performance directly depends on the power that corresponds with ventilatory threshold and VO_2max.

Keywords: cycling performance, peak power output, ventilatory threshold, VO2max, exhaustion

1. Introduction

The range of training and racing exercise intensities (Hill, Poole & Smith, 2002) can be divided in four areas based on their distinct metabolic profile. Work rates between $40\%VO_2max$ and at, or below, ventilatory or lactate thresholds ($70-80\%VO_2max$) demonstrates rapid VO_2kinetics and reaches a steady state within 3 min in healthy subjects (Whipp & Wasserman, 1972). These work rates can be defined as moderate intensity exercise. The heavy exercise intensity domain which refers to work rates above the lactate and/or ventilatory thresholds after the initial rapid VO_2 kinetics response, a slow component of VO_2 kinetics, results in a delayed submaximal steady state (Leclair, Mucci, Borell, Baquet, Carter & Berthoin, 2010). The severe exercise intensity domain is characterized by the attainment of VO_2max whereas extreme exercise intensity ($>120\%VO_2max$) due to early fatigue development and the resulting short exercise duration, prevents the attainment of VO_2max (Hill et al., 2002; Poole, Ward, Gardner &Whipp, 1988). These exercise domains have been shown to be useful to assess exercise tolerance, prescribe exercise and predict competition performance (Jones & Carter, 2000). During the preparatory training period, cyclists traditionally increase training volume to induce an overload in the training stimulus with intensities in the moderate intensity domain (Faria, Parker, Faria, 2005). When all the adaptive responses on the cardiorespiratory parameters (which limit the endurance performance plateau after the application of an increased training volume), cyclists encompass gradually increased interval training sessions to further increase their training load. Interval training usually employs intensities from the heavy and severe exercise intensity domain (Linsay, Hawley, Myburgh, 2002) and rarely from the extreme intensity domain (Tabata, Nishimura, Kouzaki, 1997). It has also been found (Tabata et al., 1997) that a high intensity intermittent training program achieved better gains in VO_2max ($+7ml.kg^{-1}.min^{-1}$) compared to a program ($70\%VO_2max$) of 60 min moderate-intensity cycling, 5 hours per week for 6 weeks ($+5ml.kg^{-1}.min^{-1}$). The potency of high intensity ($>90\%VO_2max$) interval training (HIIT) to induce rapid changes in exercise capacity and skeletal muscle metabolism has been also examined by Gibbala and McGee (2008). Short term HIIT was superior to continuous with submaximal intensity training in the criterion performance and metabolic adaptations as well. It is well established though that in order to maximize the adaptations from the training program, exercise intensities for the intermittent form of exercise, may range between 90-100%VO_2max. A recent review (Midgley, McNaughton & Wilkinson, 2006), suggested that time of exercise spent at a high percentage of VO_2max, might place maximal stress on the physiological processes and structures that limit VO_2max, providing an optimal stimulus for adaptation. Due to large inter-individual variability of time to exhaustion at 100%VO_2max (tlimit 100), adaptive training response needs consideration as it may be different. Tlimit 100 in elite, trained and untrained cyclists have been studied (Billat, Faina, Sardella, Marini, Fanton, Lupo, Faccini, De Angelis, Koralszstein & Dalmonte, 1996; Pereira-Costa, De Matos, Coelho Pertence, Almeida Neves & De Lima,2011; Caputo, Mello & Denadai, 2003; Leclair et al., 2010). However, studies examining the time to exhaustion in elite cyclists at 90%VO_2max (tlimit 90), which is the possible exercise boundary between heavy and severe exercise domain, are limited. Workloads also corresponding to 90-100%VO_2max, after an incremental VO_2max test to exhaustion, are a common practice and heavily recommended by the scientific community for interval training for all levels of road cycling performance (Faria et al., 2005). The wide range of variability of time to exhaustion at these exercise intensities may differentiate the resulting adaptations. The purpose of the present study was to examine: a) the time of exhaustion at 90 and 100%VO_2max in a homogenous group of elite cyclists and b) the contribution of selected physiological parameters on 3 km race performance. We hypothesized that variability of tlimit 90 and tlimit 100 will be limited in elite cyclists and these parameters may explain most of the race performance differences as they depend on the anaerobic and cardiorespiratory capabilities of the cyclists.

2. Material and Methods

2.1 Subjects

Eleven male (national team level) road cyclists volunteered to participate in the study. They all trained systematically for 4-5 years, 7-10 sessions per week and 500-650 km per week. All the testing trials were performed during pre-competition period. Mean age ± SD, height and body mass values were 17.7 ± 0.47 years, 176.3 ± 7.43 cm and 66.9 ± 4.9 kg respectively. Following the explanation of the experimental procedures, the associated risks, and the benefits of participation, all subjects gave written informed consent. The participants were instructed avoid eating for at least 3 h before testing and not drink coffee or taking any supplements containing caffeine for at least 8 h before trials. The subjects were also instructed to consume high carbohydrate (CHO) foods in the 48 h before each trial. The study protocol was approved from the university's ethical committee and all procedures were performed in accordance with the ethical standards of the Helsinki Declaration of 1975 as revised in 1983.

2.2 Experimental Design

All subjects performed, on a cycle Velotron Pro ergometer (Racermate Inc. USA), 3 exercises until exhaustion: one maximal graded test, and in random order, 2 constant load exercises at the workloads corresponding to 90 and 100%VO_2max. The 2 constant load exercises were carried out at the same time of day and were separated by at least 5 days. All measurements were completed within a 2-week period. During all tests, the subjects were instructed to maintain a cycling cadence 90 – 100 rpm (as in training and racing) although the work load was electromagnetically adjusted and was independent of the pedaling cadence. Elite cyclists seem to prefer a pedaling cadence within this range. Saddle height was adjusted to allow slight flexion of the knee at the lowest level of the pedal cycle and was kept constant for each participant during all testing sessions. The subjects used their own pedals and cycling shoes.

2.3 Cardiorespiratory measurements

During each exercise test, respiratory gas exchanges were measured using an automated gas-analysis system (Cosmed Quark cpet, Italy). After testing, the recorded values of ventilation (VE), oxygen uptake (VO_2) and carbon dioxide production (VCO_2) were stored for further analyses. Before and after each test, the analyzers were calibrated according to the manufacturer's instructions by using medical precision-analyzed gases, which spanned the expected O_2 and CO_2 concentration ranges. The pneumotachograph was calibrated before each test with a 3-L calibration syringe on different flow rates. Heart rate was measured and recorded with a coded heart rate monitor M430 (Polar, Kempele, Finland). For data analyses VO_2, VE, VCO_2 and Heart Rate (HR) values were averaged every 10 seconds.

2.4 Incremental test

The VO_2max, the maximal power (Pmax), the power which corresponds to VO_2max (PVO_2max) and the power at the ventilatory threshold (PVT) were determined during an incremental test to exhaustion. Subjects performed a 5-minute warm up at 100 W followed by a 5-minute rest**.** Then the incremental test started at 100 W with 30 W increments every 2-minute. The highest VO_2 value, obtained during the incremental exercise test, was recorded as the subject's VO_2max which also elicited a heart rate within ±10bpm of age-predicted HRmax, a Respiratory Exchange Ratio (RER) greater than 1.1, a blood lactate (5 min post exercise) concentration >9 $mmol.min^{-1}$ (Messonnier, Freund, Denis, Dormois, Dufour & Lacour, 2002).and finally a score on the completion of the test equal to, or greater than, 19 in the 15 grade Borg scale (Borg & Ottoson, 1986). The PVO_2max was visually determined as the lowest power associated with VO_2max attainment. In cases where the last workload was not completed, PVO_2max was determined by the following equation (Kuipers, Verstappen, Keizer, Guerten& Van Kraneburg, 1985).

$$PVO_2max = Wfinal + (t/120*30)$$

In this equation, Wfinal (measured in watts) is the last exercise intensity completed for 120 sec and t is the number of seconds that the final uncompleted exercise intensity was sustained.

PVT was determined by at least 2 different and isolated examiners. Criteria described in other studies were used for the PVT detection (Davis, 1985; Wasserman, Whipp, Koyal & Beaver, 1973). The PVT was primarily determined as the VO_2 or work load at which VE began to increase nonlinearly. To check the onset of hyperventilation other subsidiary criteria were used such as: 1) a systematic increase of VE/VO_2, 2) a nonlinear increase of VCO_2 and 3) a systematic decrease of $FECO_2$. The highest test-retest reproducibility (r=0.93) and the closest correlation (r=0.96) with LT have been previously reported (Sucec, 1982; Caiozzo, Davis, Ellis, Azus, Vandagriff, Prietto & McMaster, 1982). where ventilatory transients, such as FEO_2, VE/VO_2 and $FECO_2$, VE/VCO_2 are used for the PVT detection. When a two-minute incremental protocol is employed and before a systematic increase of either VE/VO_2 or VE/VCO_2 with a concomitant decrease of $FECO_2$,the workload can be easily defined.

2.5 Constant load exercise

Each constant load exhaustive exercise was preceded by a 10-minute warm up period at 80-100 W intercepted by 6-8 minute of passive recovery. Constant work load exercises corresponding to 90 and 100%VO_2max were carried out in random order. Time to exhaustion was determined to the nearest second as the time between the start of exercise and the time when the subjects were not able to move pedals. Respiratory data and heart rate were monitored throughout the test duration. Subjects were cooled using a cooling fan and were free to drink water ad libitum. Subjects were unaware of the elapsed time. However, strong verbal encouragement was given to extend exercise time as long as possible.

2.6 Time trial performance ride

Each rider had previous experience of racing on wooden 250 m lap indoor track and had rested for 2 days prior to the time trial. The 3 km time trial was undertaken by all cyclists (n=11) on the same day and within 5 days of their last laboratory constant test. Each rider started the trial individually from a supported standing start and was instructed to try to produce maximal effort. During the ride, subjects were able to observe time elapsed (min:sec). All cycle skeletons were made from light carbon fiber, with closed Mavic front and rear wheels, vittoria cx pista tubes with 12 bars pressure. All cyclists were wearing aerodynamic helmets and clothing. During the race trial ambient temperature and pressure were 27^{o} C and 764 mmHg respectively. Each time trial was timed manually by 3 timers. The average timing value was used for further analyses.

2.7 Blood lactate sampling and analysis

Finger tip blood samples were taken 5 minutes after the completion of VO_2max and the constant load tests. The concentration of lactate was measured enzymatically (Dr Lange

Cuvette Test LKM 140) using the LP 20 Plus mini photometer (Dr Lange, Germany). Blood was taken using 10 ml end-to-end capillaries and placed in a reagent solution which hemolyzed the blood. Lactate was processed in a reaction producing quinonimin, in proportion to the amount of lactate in the sample, and the concentration of quinonimin was read off in an LP 20 Plus apparatus at 540 nm (576 THz) after a 4-6 min reaction time.

2.8 Statistical analyses

The experimental data are presented as mean ± SD. Mean value comparisons were carried out with the paired Students t test (SPSS version 21). Relationships between 3 km performance times and selected physiological variables were analyzed with Person product moment correlations and simple linear regression analyses. Results were considered significant when $p<0.05$.

3. Results

The mean values for the metabolic and performance data for the 11 cyclists are presented in Table 1. The tlimit 90 and tlimit 100 standard deviations (±466.58 and ±53.29), coefficients of variation (47.24% and 18.46%) and the values range (1395 and 184) were large. The homogeneity of the subjects can be confirmed by the low CV of VO_2max (3.7%) and t3km (3.11%).

Table 1: Mean ±sd, CV and range of metabolic and performance values (n=11)

	VO_2max ($ml.kg^{-1}.min^{-1}$)	**Pmax (watt)**	**pVO_2max (watt)**	**PVT (watt)**	**pVO_2max (watt/kg)**	**t3km (sec)**	**tlim 90 (sec)**	**tlimit 100 (sec)**
Mean	69.77	389.09	376.36	244.55	5.63	219.48	987.73	288.64
SD	2.58	27.73	32.23	36.98	0.25	6.82	466.58	53.29
CV	3.7	7.13	8.56	15.12	4.37	3.11	47.24	18.46
Range	8.05	90	115	110	0.83	18.79	1395	184

Pmax: last work load during VO_2max test, pVO_2max: power output at VO_2max, PVT: Power at ventilatory threshold, t3km: indoor 3km race performance time, tlimit 90: duration of exercise to exhaustion at 90%VO_2max, tlimit 100: duration of exercise to exhaustion at 100%VO_2max.

Cardiorespiratory and metabolic parameters mean values (±sd) are shown in Table 2. During the final minute at tlimit 100, trial subjects reach VO_2max (incremental test value 69.77±2.58 $ml.kg^{-1}.min^{-1}$ versus tlimit 100 value 68.75±3.35, $p<0.05$). The power output at 90%VO_2max and the duration of effort at this workload were not sufficient to make the subjects work close to VO_2max values ($p>0.05$); see Table 2. Mean maximum blood lactate concentration, maximum heart rate value and the maximum volume of expired air did not differ between incremental, tlimit 90 and tlimit 100 ($p>0.05$); see Table 2.

Table 2: Cardiorespiratory and metabolic parameters mean ±SD values for the incremental and tlimit trials

Parameters	Incremental (a)	tlimit 90 (b)	tlimit 100 (c)	Significant difference
VO_2max ($ml.kg^{-1}.min^{-1}$)	69.77±2.58	62.55±2.17	68.75±3.35	a/b* c/b*
Lactate ($mmol.lit^{-1}$)	14.21±2.65	12.59±3.5	15.07±2.9	
HRmax (b.p.m)	196±8.7	189.9±9.46	191.18±7.53	
VE ($l.min^{-1}$)	177.55±13.22	159.9±16.14	177.3±13.67	

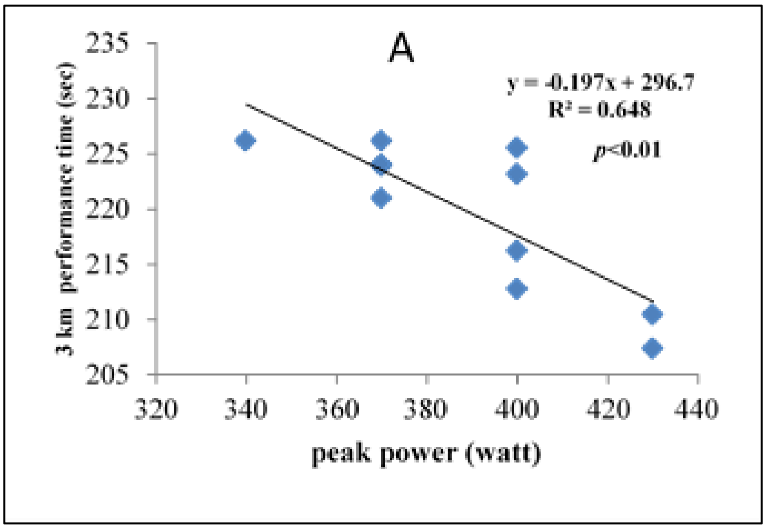
*p<0.05

Performance time for the 3km race trial was highly inversely correlated (r= -0.83, p<0.01) with PVT (Table 3). The SEE of t 3km on pVT was 3.99 seconds (p<0.01, n=11). PVT alone explained 68.7% of the 3km performance variance (Figure 1B). Table 3 also shows the highly significant relationship (Figure 1 A) between Pmax and t 3km (r=-0.80, p<0.01). Tlimit 90 (r=0.16, p>0.05) and tlimit 100 (r=0.08, p>0.05) did not correlate with t3km (Table 3). The absolute value of VO_2max ($ml.min^{-1}$) was inversely, although not significantly (p>0.05), related with tlimit 90 (r=-0.49) and tlimit 100 (r=-0.23).

Table 3: Coefficients of correlation (r) within tlimit 90, tlimit 100, VO_2max, PVT, Pmax, RPmax and 3 km race performance (n=11)

Variables	tlimit90 (s)	tlimit100 (s)	VO_2max ($ml.min^{-1}$)	PVT (watt)	Pmax (watt)	RPmax (watt)	3 km (s)
tlimit 90 (s)	1	0.40	-0.49	-0.36	-0.51	0.14	0.16
tlimit 100 (s)		1	-0.23	-0.19	-0.13	0.27	0.08
VO_2max ($ml.min^{-1}$)			1	0.68^{+}	0.87^{*}	0.43	-0.59
PVT (watt)				1	0.81^{*}	0.61^{+}	-0.83^{*}
Pmax (watt)					1	0.70^{+}	-0.80^{*}
RPmax ($watt.kg^{-1}$)						1	-0.58
3 km (s)							1

PVT: Power at ventilatory threshold, Pmax: maximal work load during incremental test, RPmax: maximal power relative to body mass.
$^{+}p<0.05$, $^{*}p<0.01$



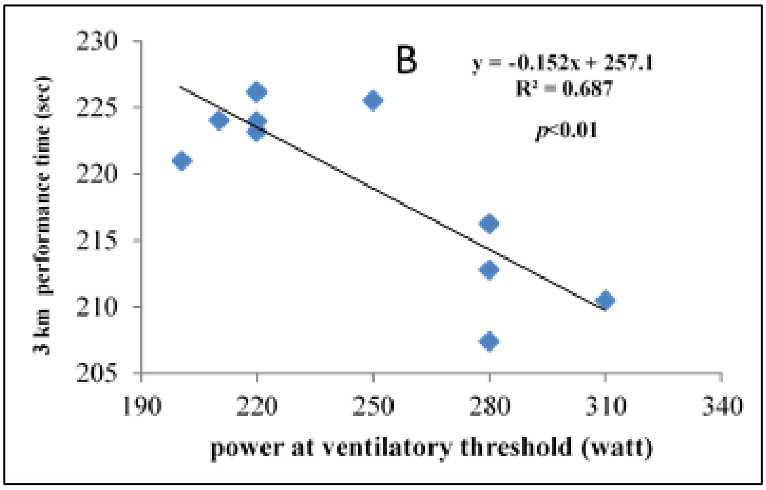


Figure 1: The linear relationships between 3 km time trial performance time (sec) and (A) peak power output (W) and (B) power output at ventilatory threshold in 11 elite cyclists. Data fitted with a line of best fit calculated from the linear regression of time trial performance time on peak power (R^2=0.648, p<0.01) and power at ventilatory threshold (R^2=0.687, p<0.01)

4. Discussion

The purpose of this study was to investigate the time to exhaustion at the 90% and 100% VO_2max and the contribution of selected cardiorespiratory parameters with 3000 m race time in a group of national level endurance cyclists. The tlimit 100 values measured in this study are in agreement with those measured in the literature for cycling (Billat et al., 1996; Caputo et al., 2003). The considerably lower mean value of the tlimit 100 reported by others (Pereira-Costa et al., 2011; Leclair et al., 2010) may be due to the performance level of the studied subjects. As stated, (Caputo, et al., 2003) tlimit 100 of a group of untrained individuals was significantly lower in cycling. In sedentary individuals (Messonnier et al., 2002) have been reported that the tlimit at 100%VO_2max during cycling was positively correlated with the lactate exchange and removal abilities. In these individuals, the lactate exchange ability was moderately correlated with capillary density and with the number of capillaries in type I muscle fiber area (Messonnier et al., 2002). It is possible that endurance training modifies these factors, increasing the maximal duration of cycling exercise at 100%VO_2max. Maximal accumulated oxygen deficit (MAOD), aerobic power, VO_2 kinetics, gross efficiency, muscle structure, energy metabolism and neuro-muscular activation have also been proposed as possible physiological mechanisms limiting tlimit 100 for cycling exercise (Caputo et al., 2003; Pereira-Costa et al., 2011; Leclair et al., 2010). The variability of the tlimit VO_2max in runners was only 26, 44, and 12% explained by differences in anaerobic capacity, running velocity at ventilatory threshold and running velocity at VO_2max respectively(Hill & Rowell, 1996a). The variability of the tlimit 100 was also poorly (<7%) explained by the variables evaluated in this study. This makes it difficult to study the physiological mechanisms that drive the decision of a subject to terminate early or to extend the effort at the power output associated with VO_2max. The variability however, of tlimit 90 was better explained (25%) by the cardiorespiratory variables (VO_2max and Pmax) suggesting that aerobic power has a greater contribution to this (90%VO_2max) exercise domain. To our knowledge, no previous study has investigated the total time to exhaustion at 90%VO_2max in elite cyclists. Surprisingly, tlimit 90 and tlimit 100 were not correlated ($r=0.4$, $p>0.05$). Assuming that physiological explanation for the termination of the effort may differ considerably between cyclists, it is likely that those cyclists with longer effort at a higher power output may not present the same performance outcome at lower exercise intensities.

Tlimit 100 was inversely, although not significantly, related to VO_2max ($r=-0.23$). This experimental finding is consistent with other studies (Billat et al., 1996) as they have also reported a modest negative correlation ($r=-0.24$) of VO_2max with tlimit 100 in a group ($n=9$) of elite cyclists. The authors (Billat et al., 1996) suggest that regardless of the type of exercise, tlimit at VO_2max depends on VO_2max.

The large inter-individual variability of the tlimit 100 of the present study (18.4%) is consistent with previous studies which reported a range of 14 to 40% of CV values (Pereira-Costa et al., 2011; Billat et al., 1996; Leclair et al., 2010; Hill & Rowell, 1996a, Hill & Rowell, 1996b; Caputo et al., 2003). The larger CV value of 47.2% of tlimit 90 cannot be precisely explained by the data of the present study. We can hypothesize though, that since tlimit 90 correlates higher with VO_2max and Pmax compared with tlimit 100, a marked difference of the contribution of the metabolic pathways to energy demands of this exercise intensity, as well as oxygen kinetics, may be responsible for this. Billat et al. (2000) observed that during running at 100%VO_2max the time necessary to reach exercise VO_2 was significantly positively related ($r=0.94$) with the tlimit100%VO_2max. Numerous published studies (Wenger & Bell, 1986; Stepto, Hawley, Dennis & Hopkins 1999; Hill, Williams & Burt, 1997; Laursen& Jenkins, 2002) propose interval training session's intensity between 85 to 100%VO_2max for the improvement of endurance capacity. It is also well established that the biochemical and physiological adaptations after endurance training are the result of the increased muscle cell energy demands (Coyle, 2000). The findings of the present study question the uniformity of training adaptations at 90 and

100% VO_2max. As athletes have significantly different relative demands on particular metabolic pathways within muscle cells, should they expose themselves to the same training duration? In line with this, others have also reported (Billat, Flecher, Petit, Muriaux & Koralsztein, 1999;Smith, McNaughton & Marsshall, 1999) significant improvements of the physiological variables and performance in already trained subjects and proposed fractions of the tlimit 100 i.e. 50% and 60% for HIIT.

Mean VO_2max value during tlimit 90 was lower compared with the corresponding values of tlimit 100 and peak VO_2 value during the incremental test. Our results were consistent with those previously published (Morton & Billat, 2000) with runners during tlimit exhaustive trial at 90%VO_2max; 6 subjects out of 10 were not able to reach VO_2max as measured in the incremental test. All the subjects of the present study reached VO_2max values during tlimit 100 compared with maximal VO_2 values during incremental test. VO_2max values were also elicited during exhaustive tlimit at 100%VO_2max trials for cycling (Pereira-Costa et al., 2011; Billat et al., 1996) and running exercises (Billat, Renoux, Pinoteau, Petit & Koralsztein, 1995; Hill et al.,1997). In a review (Midgley et al., 2006), suggested that the time spent at VO_2max intensity during training might place maximal stress on the physiological processes and structures that limit VO_2max. Further research may be needed to clarify whether longer interval exercise periods with power/velocity at 90%VO_2max are necessary to induce the same physiological adaptations seen for training intensities at vVO_2max or pVO_2max.

The mean blood lactate (15.07 vs 12.59 $mmol.l^{-1}$) and the pulmonary ventilation values (173.3 vs 159.9 $l.min^{-1}$) of the studied sample for the tlimit 100 and tlimit 90 trials were significantly higher. The accumulation of metabolites related to the process of muscular fatigue during high-intensity exercise performance may partly explain the lower tlimit 100 compared with tlimit 90 (Bentley, McNaughton, Thompson, Vleck, & Batterham,2001). The increased pulmonary ventilation during tlimit100 serves to compensate for the heavier O_2 demand of the higher exercise intensity, as well as to help alveoli to equalize the higher CO_2 pressure which was created due to enhanced metabolism.

Interestingly, the cyclists' performance of the 3000 m time trial was strongly correlated with the PVT (r=-0.83) and Pmax (r=-0.80). The findings of this study are in accordance with a similar design study which reported the importance of cardiorespiratory adaptations for the high-level endurance cycling performance (Poole et al.,1988). Significant correlations of a 10 km uphill cycling time trial with PVT and Pmax that have been expressed as relative to the exponent of mass 0.79 have also reported (Pereira Costa et al., 2011). A similar study (Hawley & Noakes, 1992) revealed that a highly significant relationship exists between maximal power output attained during a laboratory test to exhaustion and 20 Km cycling time trial performances. Using a group of amateur, well-trained cyclists, another study (Bishop, Jenkins, & Mackinnon, 1998) reported also that maximal power output was a useful tool in the prediction of endurance cycling performance. Furthermore, for a longer (40 km) cycling time trial, (Hoogeveen&Hoogsteen, 1999) reported a similar (r=-0.80) to the present study, relationship of the PVT with the time trial performance. Based on the results of our study in elite cyclists, PVT can explain 69% of the variability of the 3 km performance. Besides those physiological parameters, physical factors such as air and rolling resistance, frictional losses, resistance due to gravity and pacing strategy, influence the overall time trial performance (Atkinson, Davison, Jeukendrup&Passfield, 2003).

Using a homogenous and highly trained group of subjects, in terms of VO_2max (69.77±2.58 $ml.kg^{-1}.min^{-1}$, CV = 3.7%), the present study failed to notice any significant correlation of VO_2max with 3 km performance time ($r=0.59$, $p>0.05$). Studying competitive cyclists, for a longer though distance (10km), Pereira Costa et al. (2011), reported similarly low correlations. Other studies (Hawley & Noakes, 1992; Balmer, Davison & Bird, 2000) for longer cycling time trials, reported higher correlations of VO_2max with performance time (r=-0.91-0.99). This discrepancy may be the combined influence of VO_2max heterogeneity of the subjects used for the earlier studies, as well as the lower contribution of aerobic metabolism to the total energy demands of 3 km time trial, compared to 16 and 20 km time trials.

5. Conclusions

In summary, the findings of this study indicate that: a) if cyclists' training intensity is based on %VO_2max individual determination of the tlimit at the %VO_2max has to be considered due to the wide range tlimit values to exhaustion b) 3 km indoor cycling performance time can be significantly lowered if the athlete improves PVT and Pmax through training.

6. Recommendations

Further research with athletes of different physical and physiological characteristics and various performance levels is also required in order to draw conclusions about the factors that determine the inter-individual variability for tlimit at various percentages of VO_2max.

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Conflicts of Interest
The authors declare no conflict of interest.

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