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RELATIONSHIP BETWEEN MAXIMAL EXERCISE PARAMETERS AND INDIVIDUAL TIME TRIAL PERFORMANCE IN ELITE CYCLISTS WITH PHYSICAL DISABILITIES

Pieter-Henk BOER[1] & Elmarie TERBLANCHE[2]
[1] *Department of Sport Science, North West University, Mafikeng, Republic of South Africa*
[2] *Department of Sport Science, Stellenbosch University, Stellenbosch, Republic of South Africa*

ABSTRACT

*It is widely accepted that the ventilatory threshold (VT) is an important determinant of endurance performance. This study investigated whether the physiological responses during a 20km time trial (TT) in cyclists with physical disabilities (medium to high functional ability) relate to their VT and also to determine which variable(s) best predict their performances. Nine elite cyclists (19±2yrs; 170±10cm; 62±8kg; 53±8 ml.min^{-1}.kg^{-1}) participated in the study. Subjects performed a ramped exercise protocol (20W·min^{-1}) to exhaustion and a self-paced, 20km TT on the Velotron cycle ergometer. Mean values for heart rate (HR) (181±8bpm) and %HR max (92±3.13%) for the 20km TT were not significantly different when compared to values at VT (HR: 180±8bpm, %HR max: 93±1.17). However, the mean power output (PO) during the TT (199±42W) was significantly lower ($p<0.05$) than the PO at the VT (250±65W)***.** *Peak power output (PPO) predicted 83% of the variance when performance was measured as 20km average watts and was the only significant variable, amongst all VT and maximal variables, included in the stepwise multiple regression model. These results suggest that the self-selected exercise intensity of cyclists with physical disabilities during a 20km TT and their VT is similar when exercise intensity is expressed as average HR and %HR max. Secondly, it has been shown for the first time that, similar to able-bodied cyclists, PPO at VT correlates best with TT performance in cyclists with disabilities.*

Key words: Cycling; Ventilatory threshold; Time trial; Disabilities; Peak power output; Performance.

INTRODUCTION

The ventilator threshold (VT), defined as the first inflection point in pulmonary ventilation when expressed as a function of oxygen uptake, has been well recognised as an important determinant of performance capacity in endurance sport (Tanaka & Matsuura, 1984; Reybrouck *et al*., 1986; Haogeveen *et al.*, 1999; Milani *et al.*, 2006), even more so than maximal oxygen consumption (Tanaka *et al*., 1986; Bassett & Howley, 2000). VT is commonly used for exercise training prescription, as work rates below this threshold is associated with relatively steady blood lactate levels and thus indicates the most tolerable work rates that can be sustained for prolonged periods of time (Whipp, 1994). Similarly, the lactate threshold (LT) is also considered a valid indicator of endurance performance (Yoshida *et al.*, 1987). However, although some studies demonstrate that the exercise intensity at LT under-represent cycling time trial (TT) intensity (Coyle *et al.*, 1991; Kenefick *et al.*, 2002), as well as cycling intensity during field performance events (Nichols *et al.*, 1997). These are not universal findings (Lorenzo *et al.*, 2011).

Regardless of the specific method used to determine LT (fixed blood lactate threshold e.g. OBLA, first rise in blood lactate above resting values, MLSS, or a rapid change in the inclination of blood lactate, etc.), some researchers found lactate concentrations much higher than those presented by LT during a 20km or 40km TT. In fact, Kenefick *et al.* (2002) reported in their study of regionally competitive cyclists and during a 20km TT, lactate values of 10mmol·L^{-1}; Nichols *et al.* (1997) reported lactate values of 7mmol·L^{-1} in women master athletes (20km TT) and Coyle *et al.* (1991) in young male cyclists (40km TT) values of 7-8mmol·L^{-1}. These values were measured at 5minute intervals during the TT. These studies suggest that LT is not representative of race pace during a cycling TT even though it may be related to performance. On the other hand, Lorenzo *et al.* (2011) asserted that VT methods correlated less well than LT with TT performance. These inconsistent findings highlight the fact that many factors influence the estimation of LT and VT, among other, environmental temperature, duration of event and training status of the cyclists.

Notwithstanding the continuing debate on the relation between the various thresholds and endurance exercise performance, many researchers opt to use the VT (calculated by various ventilatory variables). There are various ways to determine VT (respiratory exchange ratio [RER], V slope method and ventilatory equivalent for oxygen), but no consensus exists on the best method (Solberg *et al.*, 2005). Amann *et al.* (2004) demonstrate that using RER=1.00 to express VT provide a significant prediction of performance in a 40km TT (r^2=0.57; p=0.0001). Solberg *et al.* (2005) found that RER=1.00 was the most reliable respiratory variable to determine VT because of its low inter-observer variability. Furthermore, the non-invasiveness of this method and ease of calculation are also considered important reasons to apply this method.

PURPOSE OF THE STUDY

The objective of this study was therefore to evaluate the suitability of this method (VT expressed as RER=1), to predict TT performance in other populations, such as cyclists with disabilities. Therefore, the primary aim of this study was to identify the exercise intensity that was freely chosen by elite cyclists with disabilities during a 20km TT relative to the VT. The secondary aim was to explore which laboratory-based measure (maximum or VT-based variable) best predicts performance in a 20km TT (expressed as the average PO during the TT).

METHODOLOGY

Subjects

The data of 9 (8 men and 1 woman) elite cyclists with disabilities (4 with amputations, 4 with cerebral palsy and 1 with visual impairment) were analysed in this study (Table 1), while they were in the competition phase of the training year. The sample was categorised according to functional ability (Table 2), and in accordance with the classification system of the UCI (Union Cycliste Internationale). The study sample was uniformly dispersed between medium to high functional ability (T2, C5, C4). T2 is the highest level of functional ability in the tricycle group, whilst C5 is the most functional in the cycling group. One participant was grouped under a separate column namely visually impaired (VI). All cyclists were endurance trained and familiar with TT cycling. All the subjects trained regularly on an indoor stationary cycle and thus were familiar with the current testing procedures. The study was conducted during a para-cycling training camp. Permission was obtained from Cycling South Africa to use the data. The participants signed a consent form informing them of the purpose and procedures of the testing protocols and they also consented that the data may be used for research purposes.

***TABLE 1*: DESCRIPTIVE STATISTICS OF PARTICIPANTS**

Item	**Mean (s)**	**Range**
Age (years)	19 (±2)	16-23
Body mass (kg)	62 (±8)	52-74
Height (cm)	170 (±10)	155-187
BMI ($kg{\cdot}m^{-2}$)	18 (±2)	17-21
VO_2 max ($ml.min^{-1}.kg^{-1}$)	53 (8)	39-64

BMI = Body Mass Index

***TABLE 2*: CLASSIFICATION OF PARTICIPANTS ACCORDING TO FUNCTIONAL ABILITY**

Group	**T2**	**C4**	**C5**	**VI**
Number	2	3	3	1

T2 = Highest classification for tricycle subgroup; C4 = 2nd Highest classification for cycling subgroup; C5 = Highest classification for cycling subgroup; VI = Visually Impaired.

All participants were tested on 2 consecutive days in the mornings. They were instructed not to exercise in the 3 days preceding the testing days. They were also told to refrain from any caffeine and alcohol intake 12 hours prior to testing and any meals 2 hours prior to testing. During the first visit subjects performed a VO_2 max test to determine maximum oxygen consumption, peak power output, power to weight ratio, minute ventilation and maximum heart rate. VT (determined at RER=1) was expressed relative to all the maximal responses during the VO_2 max test. The following day, the participants performed a 20km TT.

Measures and procedures

Body mass and height were measured with the Seca stadiometer and scale (Seca, Hamburg, Germany) to the nearest 0.1cm and 0.1kg. The participants wore cycling attire during these measurements. Both exercise tests were performed on the Velotron cycle ergometer (Velotron Electronic Bicycle Ergometer, Racermate, Seattle, WA, USA). This ergometer provides resistance via an electronic current breaking a heavy (55lb) large diameter flywheel. The pedal system of each cyclist was fitted to the ergometer and the ergometer settings were matched to their own bike set-up. The laboratory was set at an air temperature of 19 degrees for both tests. Participants were allowed to drink water after the warm-up period for both tests. Participants were encouraged to cycle to exhaustion during the VO_2 max test and to cover the 20km TT in the shortest possible time. In both instances, participants were encouraged and motivated during the test.

VO_2 max test

Participants completed a 15-minute warm up at a resistance of 80 watts. Gas exchange variables were continually measured (breath by breath) with the Cosmed Quark CPET (Cosmed, Rome, Italy) metabolic system. The system was calibrated with known volumes and concentrations of gasses (79% N_2, 16% O_2, 5% CO_2) prior to each test. Subjects were fitted with the Cosmed heart rate (HR) monitor, with HR also continuously measured. Subjects performed a ramped protocol ($20W \cdot min^{-1}$) commencing at an initial resistance of 50 watts and were instructed to maintain the cadence at 80 to 100 revolutions per minute (rpm). Participants cycled until volitional exhaustion. The test was considered maximum if all of the following criteria were met: (1) HR max was 90% or more of age predicted maximum HR; (2) absolute VO_2 increase of less than $150ml \cdot min^{-1}$ with increasing work load and (3) an RER value of more than 1.15. The test was terminated when the subject stopped pedalling or when the cadence dropped below 70rpm. The ventilatory threshold was determined at an RER where the value was consistently above 1.

Time trial test

Participants completed a 10-minute warm up at a resistance of 80 watts. They were asked to complete the TT as fast as they could and were assisted by trained exercise physiologists to shift gears so that optimum cycling efficiency and preferred intensity was reached. Both participants and exercise physiologists were naïve regarding the results of the maximal exercise test on the previous day. They did, however, receive visual feedback via a computer screen on the speed, distance, time and workload throughout the TT. Performance variables evaluated were: time to completion; average and peak power; average and peak HR; and average and peak speed.

Analysis of data

Data were analysed with a commercially available statistical software program (SPSS 20.0, SPSS Chicago, IL, USA). Descriptive data are presented as mean and standard deviations (SD). Paired t-tests were done to detect significant differences between PO, power to weight ratio (P:W) and HR at VT, and average values of these variables during the TT. Paired t-tests were also performed to detect significant differences between the average exercise intensity, expressed as %HR max during the TT and VT (expressed as %HR max) of the VO_2 max test. Lastly, a stepwise multiple regression analysis was performed to determine which laboratory-derived variable (VT and maximal variables in the VO_2 max test) predicted TT performance (expressed as 20km average PO) the best.

RESULTS

All the participants reached well over 90% of their age predicted HR max (mean value of 98±4%) during the maximal aerobic capacity test. They also achieved RER values over 1.15 (mean value 1.2±0.03). Lastly, all participants' absolute VO_2 values demonstrated a plateau during the last minute of the exercise test despite an increase in workload (<150ml·min^{-1}). All descriptive statistics for the VO_2 max test (values at VT and at exhaustion) are displayed in Table 3.

***TABLE 3*: VALUES REPRESENTATIVE OF THE VT, MAX AND VT AS % OF MAXIMAL VALUE**

Variable	**Mean (s) at VT**	**Range**	**Mean (s) at exhaustion**	**Range**
PO (W)	250 (±65) 80% of max	157-360	312 (±69)	193-423
P:W (W·kg-1)	4 (±1) 80% of max	3-5	5 (±1)	4-6
HR (bpm)	180 (±8) 93% of max	165-193	193 (±8)	175-206
VO_2 (ml·min-1·kg-1)	49 (±7) 92% of max	39-61	53 (±8)	39-64
VE (l·min-1)	93 (±16) 67% of max	63-111	139 (±34)	90-205

PO = Power Output; P:W = Power to Weight; HR = Heart Rate;
VO_2 = Maximal Oxygen Consumption; VE = Minute Ventilation; VT = Ventilatory Threshold.

Participants completed the 20km TT in an average time of 36 minutes and 44 seconds. Related descriptive statistics for this test are presented in Table 4.

***TABLE 4*: DESCRIPTIVE STATISTICS FOR 20KM TT**

Variable	**Mean (s)**	**Range**
Speed (km·h^{-1})	33 (±3)	28-37
Cadence (rpm)	101 (±9)	89-115
PO (W)	199 (±42)	130-256
HR (bpm)	181 (±8)	171-191

PO = Power Output; HR = Heart Rate

On average, HR was 1bpm higher during the TT compared to the average HR at VT (Table 5). Also, the percentage of maximum HR during the TT was 1% less than during the VO_2 max test. However, these differences were not statistically significant. Conversely, PO and P:W at VT were significantly higher compared to the values measured during the TT. PO at the VT was 51W more than the average watts during the TT ($p<0.05$). Similarly, mean values for the P:W ratio were 0.8 units lower during the TT ($p<0.01$).

***TABLE 5*: COMPARISON BETWEEN VT AND TT ASSOCIATED VARIABLES**

Variable	VT	TT	p-Value
HR	180 (8)	181 (8)	0.690
%HRmax	93 (1)	92 (3)	0.540
PO	250 (65)	199 (42)	0.030
P:W	4 (1)	3 (1)	0.004

HR = Heart Rate; %HR max = Percentage of Heart Rate maximum; PO = Power Output; P:W = Power to Weight ratio; VT =Ventilatory Threshold; TT = Time Trial

The multiple regression model revealed that only one variable contributed significantly to the variance observed in the independent variable. The PPO during the VO_2 max test predicted 83.2% of the variance when performance was measured as the average PO during the 20km TT ($P<0.001$).

DISCUSSION

In this study a group of elite cyclists with physical disabilities were tested in the competition phase of their training year. The main objective of this study was to determine if VT, assessed as RER=1, can be used as a predictor of performance in cyclists with physical disabilities, similarly to able-bodied cyclists. Previous studies have found that LT based variables under-estimated training intensity during a 20- or 40km TT (Coyle *et al*., 1991; Nichols *et al*., 1997; Kenefick *et al*., 2002), while Amann *et al*. (2006) considered VT based variables (using gas exchange and ventilatory variables) superior to LT-based variables in predicting performance during 40km TTs. The use of VT associated variables and the relation to TT performance has never been explored amongst trained cyclists with physical disabilities.

The results of the current study suggest that the self-selected exercise intensities of cyclists with physical disabilities during a 20km TT and their VT are similar, when exercise is expressed as average HR or %HR max and thus provide coaches a useful tool to prescribe training intensities when using heart rate monitors. Although cyclists can also use power meters to gauge and determine training intensities, it seems that VT is not a good estimate of exercise intensity when the exercise intensity during a TT is expressed as average power output. In the present study, participants were able to cycle at an average PO of 199±42 W, which was 20% less than PO at the VT. Amann *et al*. (2006) reported 13% lower values during the TT than the PO at VT (also using RER=1 and a ramped protocol). However, studies applying the LT as anaerobic marker (using incremental protocols) reported values on the other side of the spectrum. Kenefick *et al*. (2002) demonstrated that participants cycled at a 15% higher PO during the 20km TT than PO at LT (using $2mmol \cdot L^{-1}$ above baseline as LT). Bentley *et al*. (2001) also found that well trained men perform at a 20% higher PO during a 20-minute TT than at LT (measured at OBLA- onset of blood lactate accumulation).

Due to the various methods of determining LT, and the absence of exercise intensities that replicate any LT during TTs, it is understandable why Kenefick and colleagues (2002) concluded that optimal performance would most likely be accomplished if training intensities are representative of and based upon actual cycling competitions. They advised that most LT based definitions do not represent training intensity considering PO or HR during a 20km TT.

The type of testing protocol could explain a possible reason for the over-estimation of PO at VT during some VO2 max tests and the under-estimation of PO at LT during others. With a ramp protocol (current study and Amann *et al*., 2006), workload stages increased rapidly (20 and $25W{\cdot}min^{-1}$, respectively), whereas an incremental type protocol (Bentley *et al*., 2001; Kenefick *et al*., 2002) utilises larger increments (usually 30W every three minutes). Although a ramp protocol starts at a lower initial wattage, the smaller workload increments could lead to higher sub-maximal values compared to an incremental test protocol. However, similar ramped-loaded workloads and stage durations are often used in maximal tests where the VT is determined rather than the LT (Luciã *et al*., 2000; Amann *et al*., 2004; Amann *et al*., 2006; Neder & Stein, 2006). Amann *et al*. (2006) specifically showed that a ramp protocol ($25W{\cdot}min^{-1}$) and its associated VT variables are superior to an incremental LT protocol (50W increase every 3 minutes) if the purpose is to predict TT performance.

The mean VO_2 max of the study sample was $53ml{\cdot}kg^{-1}{\cdot}min^{-1}$, which is categorised as excellent based on gender and age (Hoeger & Hoeger, 2009). VO_2 values at VT were 92% of the VO_2 max in the current study indicating that participants were well trained (Milani *et al.*, 2006). Coyle *et al*. (1991) registered a similar percentage during an actual 40km TT where subjects cycled at an average of 88% VO_2 max. Coyle *et al*. (1991) further reported that the VO_2 measured at LT was 78% of maximum, well below the 88% of VO_2 max measured during the TT. Kenefick *et al*. (2002) also reported that male cyclists worked at 86% VO_2 max during a 20km TT while values measured at LT (2mmol above baseline) were 73% VO_2 max. Unfortunately the current study did not measure gas exchange during the TT, although it would have been interesting to calculate this ratio to maximum values. It does, however, seem likely that well trained cyclists register VO_2 values close to maximum (86-88%) during a 20km TT and well above LT VO_2 values (Coyle *et al*., 1991; Kenefick *et al*., 2002).

The cyclists in the present study were able to maintain a TT pace that elicited 92% of HR max, which is similar to values documented by Kenefick *et al*. (2002) (92%) and Nicholas *et al*. (1997) in women master athletes (91.6%). The able-bodied participants in the study by Kenefick *et al*. (2002) were of comparable age and experience level to the participants in the current study. Balmer *et al*. (2000) also performed a simulated laboratory 16.1-km TT and found heart rates expressed as a percentage of maximum in the 90±2% range (well trained endurance athletes). Thus, it could be argued that well trained cyclists more often than not perform at intensities close to 92% of maximum during 20km cycling TTs. These researchers suggested that traditional means of exercise prescription using age predicted maximum heart rate, underestimate training intensity, and similar to values at LT, and that actual average HR expressed as a percentage of maximum provide a better index to training intensities and race pace.

It seems then that HR at VT is more closely associated with exercise intensities during a 20km TT compared to PO at VT, considering the stabilisation of HR at more or less 92% of maximum in well-trained cyclists. Furthermore, Luciã *et al*. (2000) demonstrated that HR fluctuates only modestly during different phases of the training season in national level cyclists. They found that although performance improved (continual changes in average power output) as the season progressed, HR values measured at VT remained largely stable (pre-season: 155±3bpm; pre-competition: 156±3bpm; competition: 159±3bpm).

A multiple regression analysis was also performed to determine which variable best predicts performance. Surprisingly only one variable, namely PPO, contributed significantly and strongly to the variance (83%; $p<0.001$) observed in the independent variable. This finding, that PPO is a powerful predictor of performance, is in agreement with the study by Balmer *et al*. (2000) who also demonstrated that performance in a 16.1-km TT could be accurately predicted from PPO. Bentley *et al.* (2001) also established that 83% of the performance variance was explained by PPO, a finding with values very similar to the current study. Similarly, Amman *et al*. (2006) demonstrated amongst many LT, VT and maximum based variables, that PPO was most strongly correlated to performance.

CONCLUSION

To our knowledge, this is the first study to show that HR at VT and during a 20km TT is almost identical and that PPO, measured during a VO_2 max test is the best predictor of TT performance in well-trained cyclists with disabilities. The latter finding is consistent with previous studies in able-bodied cyclists, but has now for the first time been illustrated in cyclists with physical disabilities. These findings provide valuable practical information for these cyclists in terms of training prescription and benchmarks for race pace.

STUDY LIMITATIONS AND FUTURE STUDIES

The participants in this study were heterogeneous in terms of disability, however, there is only a limited number of elite cyclists with physical disabilities in South Africa. It was very fortunate that such highly trained cyclists with physical disabilities, who came from all over the country, could be tested. Although there were no significant differences in this study between the cerebral palsy and amputee cyclists for the various performance measures (VO_2 max, VT, PPO, P:W and PO during the TT), it should not be assumed that this would be the case in a larger sample. The small sample size may also have affected the predictive value of the multiple regression analysis.

Future studies could possibly include continuous gas exchange measurement during the TT as to compare VO_2 values measured at the VT or as a percentage of max with those of the TT, similar to the studies by Coyle *et al*. (1991) and Kenefick *et al*. (2002). Future studies could also explore whether the results found in this study are evident in a 40km TT, as well as TTs outside the laboratory. Lastly, it can be explored whether the findings of this study differ across training seasons to ascertain the dynamics of PO and HR at VT and also during the TT.

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Mr Pieter-Henk BOER: Academic Building, Block B, Office 155, Faculty of Human and Social Sciences, Department of Sport Science, North West University, Mafikeng Campus 2735, Republic of South Africa. Tel.: +27 (0)18 389 2262, Fax.: + 27 (0)18 389 2504, E-mail: pieterhenk.boer@nwu.ac.za

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