Peak power output, the lactate threshold, and time trial performance in cyclists

DAVID J. BENTLEY, LARS R. MCNAUGHTON, DYLAN THOMPSON, VERONICA E. VLECK, and ALAN M. BATTERHAM

From the Department of Sport and Exercise Science, University of Bath, Bath, UNITED KINGDOM; and the Department of Sport, Health and Exercise, Staffordshire University, Stoke-on-Trent, UNITED KINGDOM

ABSTRACT

BENTLEY, D. J., L. R. MCNAUGHTON, D. THOMPSON, V. E. VLECK, and A. M. BATTERHAM. Peak power output, the lactate threshold, and time trial performance in cyclists. Med. Sci. Sports Exerc., Vol. 33, No. 12, 2001, pp. 2077–2081. Purpose: To determine the relationship between maximum workload (Wpeak), the workload at the onset of blood lactate accumulation (WOBLA), the lactate threshold (WLag), and the Dmax lactate threshold, and the average power output obtained during a 90-min (W90-min) and a 20-min (W20-min) time trial (TT) in a group of well-trained cyclists. Methods: Nine male cyclists (VO2max 62.7 ± 0.8 mL·kg⁻¹·min⁻¹) who were competing regularly in triathlon or cycle TT were recruited for the study. Each cyclist performed four tests on an SRM isokinetic cycle ergometer over a 2-wk period. The tests comprised 1) a continuous incremental ramp test for determination of maximal oxygen uptake (VO2max) (L·min⁻¹ and mL·kg⁻¹·min⁻¹); 2) a continuous incremental lactate test to measure Wpeak, WOBLA, WLag, and the Dmax lactate threshold; and 3) a 20-min TT and 4) a 90-min TT, both to determine the average power output (in watts). Results: The average power output during the 90-min TT (W90-min) was significantly (P < 0.01) correlated with Wpeak (r = 0.91), WLag (r = 0.91), and the Dmax lactate threshold (r = 0.77, P < 0.05). In contrast, W20-min was significantly (P < 0.05) related to VO2max (L·min⁻¹) (r = 0.69) and WLag (r = 0.67). The Dmax lactate threshold was not significantly correlated to W90-min (r = 0.45). Furthermore, WOBLA was not correlated to W90-min (r = 0.54) or W20-min (r = 0.23). In addition, VO2max (mL·kg⁻¹·min⁻¹) was not significantly related to W90-min (r = 0.11) or W20-min (r = 0.47). Conclusion: The results of this study demonstrate that in subelite cyclists the relationship between maximum power output and the power output at the lactate threshold, obtained during an incremental exercise test, may change depending on the length of the TT that is completed. Key Words: INCREMENTAL EXERCISE, MAXIMUM POWER OUTPUT, BLOOD LACTATE, CYCLING, ENDURANCE PERFORMANCE

The determination of physiological variables such as the anaerobic threshold (AT) and maximal oxygen uptake (VO2max) through incremental exercise testing, and the relevance of these variables to endurance performance, is a major requirement for coaches and athletes. Maximum oxygen uptake has been used as a valid indicator of superior performance in distance runners (12), but other studies have suggested that VO2max is not a good predictor of 40-km cycle or 8-km running performance in triathletes (6,31). Furthermore, recent studies using elite cyclists as subjects have demonstrated that VO2max is not a good indicator of cycling ability (10,23). However, the peak power output (Wpeak), defined as the highest workload sustained for 2 to 3 min during progressive incremental exercise to exhaustion, has been shown to be highly related to time trial (TT) performance ranging from 21 to 40 km (3,6,17,30).

Other research groups have reported that the workload or oxygen consumption (VO2max) corresponding to set blood lactate concentrations or inflection points obtained during incremental exercise tests are better indicators of endurance performance than VO2max (8,14,15). The workload eliciting a blood lactate concentration of 4 mmol·L⁻¹ (also called onset of blood lactate accumulation (OBLA)), for example, has been used as an indicator of distance running ability (27). The Dmax lactate threshold is determined by calculating the power output corresponding to the greatest perpendicular distance from a regression line of lactate to workload as well as a straight line formed by the first and last points of the regression line (7). In two recent investigations (7,8), it was established that the Dmax lactate threshold and the OBLA were the two variables that were most related to the average power output achieved during 60 min of cycle exercise in female cyclists. Although these experiments report that either Wpeak or submaximal workloads associated with certain blood lactate concentrations are indicative of successful endurance performance, the studies are limited by not reporting Wpeak. In addition, the subjects participat-
ing in the research were of mixed ability level ($\dot{V}O_{2\text{max}}$ range, 35.5–57.9 mL·kg$^{-1}$·min$^{-1}$) and would thus differ with regard to $W_{\text{peak}}$.

$TT$ in road cycling stage events are also held over distances of 15 to 60 km as in an individual TT, and in the sport of triathlon, the cycle stage is completed over courses ranging from 20 to 180 km. Thus, in cycling and triathlon, the cycle stages range from less than 30 min to more than 240 min. Typically, most investigations have examined cycling TT performance over distances and durations less than 60 min (3,8,14). There are at present no data examining the relationship between variables obtained from an incremental exercise testing and cycle performance over short and longer duration (i.e., < 30 min or > 60 min) in well-trained specialist TT cyclists and triathletes.

In the present experiment, a group of well-trained cyclists completed a short (20 min) and long (90 min) TT as well as an incremental exercise testing procedure. These tests were implemented to establish the relationship between the workload at a number of lactate inflection points previously used to assess trained cyclists (8,14) and the average power output sustained during a long (90 min) and short (20 min) TT.

**METHODS**

**Subjects**

Nine male cyclists with the following characteristics (mean ± standard deviation (SD)) volunteered to participate in the study: age, 32 ± 3 yr; body mass, 77.3 ± 4.8 kg; and height, 185.5 ± 3.3 cm. At the time of recruitment, each subject was competing in either TT or triathlon events that were conducted over distances ranging from 16 to 90 km. The group included age group triathletes who had competed regularly in international ($N = 4$) and national ($N = 3$) level competitions or British Cycling Federation (BCF) category II cyclists ($N = 2$). The procedures were explained to the subjects both verbally and in writing. The subjects each provided written informed consent. The institutional research ethics committee approved the study.

**Procedures**

Each subject was required to complete four tests performed on an SRM cycle ergometer (Schroederer Rad MeTechnik, Weldorf, Germany) during a 2-wk period of the competition phase of the training year (June to August). The cyclists were instructed to continue to train and not deviate from their planned schedules during the course of the investigation. The four tests, each separated by at least 24 h, comprised 1) a continuous incremental ramp test, undertaken first, with the following in random order: 2), a continuous incremental lactate test, 3) a 20-min TT, and 4) a 90-min TT.

**Incremental ramp test.** The continuous incremental ramp test was used to determine $\dot{V}O_{2\text{max}}$. The test commenced following a 10- to 15-min warm-up at a self-selected intensity not exceeding approximately 50% of $\dot{V}O_{2\text{max}}$. The initial test workload was set at 150 W for 60 s, after which power output was increased by 30 W·min$^{-1}$ until exhaustion, which was always within 12 min. During the test, expired gases were continuously monitored by breath through a mass spectrometer (EX670, Morgan Medical Ltd., Gillingham, United Kingdom) for determination of $\dot{V}O_{2\text{max}}$ and respiratory exchange ratio (RER). The system was calibrated with known volumes (3 L Hans Rudolph Syringe, Hans Rudolph, Kansas City, MO) and concentrations of gas prior ($O_2$, $CO_2$, $N_2$, $Ar$) to each test. Heart rate (HR) was recorded every 5 s during the test using a portable HR monitor (Polar Vantage, Finland). Maximal exertion was deemed to have occurred if $\dot{V}O_{2\text{max}}$ failed to rise (< 200 mL·O$_2$) with a subsequent increase in workload, an RER > 1.2, and HR$_{\text{max}}$ within 5 b·min$^{-1}$ of age-predicted HR (220 – age). $\dot{V}O_{2\text{max}}$ was determined as the highest consecutive breath-by-breath $\dot{V}O_{2\text{max}}$ point obtained during any 60-s period of the test.

**Incremental lactate test.** A continuous incremental lactate test was used to determine the power output (in watts) at the lactate threshold (LT) (5), the OBLA (27), the D$_{\text{max}}$ lactate threshold (8), and $W_{\text{peak}}$ (17). The test commenced without warm-up at a workload representing 50% $\dot{V}O_{2\text{max}}$ for 3 min. After the initial 3-min stage, the required workload increased by approximately 5% of $\dot{V}O_{2\text{max}}$ every 3 min until voluntary exhaustion occurred (13). Capillary blood samples were obtained from the left ear lobe in the last 30 s of each workload as well as at the end of the test and were analyzed for whole blood lactate using a portable lactate analyzer (LT 1710 Lactate Pro, KDK Corporation, Shiga, Japan). The reliability and validity of this device has been previously determined (26).

Blood lactate concentration (in mmol·L$^{-1}$) was plotted against power output (in watts) during the incremental lactate test. A third-order polynomial curve was then constructed from the data points. The LT ($W_{\text{LTlog}}$) was determined as the power output (in watts) at which lactate increases exponentially when the log ([La$^{-}$]) is plotted against the log (in watts) (5). The OBLA ($W_{\text{OBLA}}$) was determined as the power output eliciting a lactate concentration of 4 mmol·L$^{-1}$ (27). The D$_{\text{max}}$ lactate threshold was calculated as the point (in watts) on the polynomial curve forming the greatest perpendicular distance to a straight line formed by the first and last data points (8). The $W_{\text{LTlog}}$, $W_{\text{OBLA}}$, and D$_{\text{max}}$ lactate threshold were calculated by interpolation using a custom written workbook (Microsoft Excel for Windows 7.0, Microsoft, Redmond, WA).

**Cycle TT.** The cycle TT were performed over 20 min and 90 min on the SRM cycle ergometer at a freely selected pedaling cadence. Another study has reported high reproducibility of cycle TT of short and long duration (18). The subjects refrained from any high-intensity/long-duration training for 48 h before each test. Each subject was instructed to prepare for each trial as they would for a normal competition and were instructed to consume high-carbohydrate (CHO) foods and regular quantities of fluid in the 48 h before each trial. Written guidelines were administered to each subject with regard to correct nutritional strategies.
Thirty minutes before the 90-min TT, 500 mL of fluid (Lucozade Sport, Smith Kline Beecham, Brentford, United Kingdom) containing 32 g of CHO was ingested. During the trial, a further 250 mL was consumed every 15 min to control for possible dehydration and substrate depletion (2). Body mass (in kilograms) was obtained with subjects wearing only Lycra cycling shorts using a balance beam (Weylux, England) before and after the trials to determine the extent of fluid loss (range, 0.3–1.3 kg) attributable to sweating. During both TT, electrical fans were positioned around the cyclist to allow circulation of air. Each of the trials were performed at the same time of day to control for any diurnal variation in performance and were supervised by the same researcher.

Before each test, 15 min of warm-up was allowed at a self-selected intensity not exceeding 50% VO_2max. After a 60-s period where the subject was instructed to increase the power output to approximately 70% of W_peak, the trial commenced and the subject was free to vary the power output and pedaling frequency at their own discretion. Performance was evaluated by determining the average power output that each subject could maintain for the test duration.

Each incremental test and TT was performed on an SRM isokinetic cycle ergometer calibrated using the manufacturer’s recommendations. The SRM cycle ergometer allows adjustments to be made so that the dimensions of the cyclist’s own bicycle set-up are obtained. Clipless pedals were also attached so that the cyclist could wear their own shoes.

The SRM crank system has also been confirmed as valid and reliable in determining maximal and submaximal power output data (4). Briefly, the SRM cycle ergometer is designed so that power output is calculated by the average torque of one crank revolution multiplied by the angular velocity of one crank revolution via a power control unit. The power control unit is integrated to the crank system of the ergometer. The power output is sampled at 1-s intervals and transferred to the SRM software downloaded to a personal computer.

**Statistical Analyses**

Mean and SD were calculated for VO_2max (in L·min⁻¹ and mL·kg⁻¹·min⁻¹) obtained during the ramp test. Descriptive statistics were also calculated for W_peak (in watts), W_LTlog, W_OBLA, and the D_max lactate threshold (in watts). In addition, average power output (in watts) during the 90-min (W_90-min) and 20-min (W_20-min) TT were also obtained. The relationship between W_90-min and W_20-min and each variable during the incremental exercise tests were determined using Pearson product correlations and linear regression analysis. A paired sample t-test was used to compare the W_90-min and W_20-min. Statistical significance was set at P < 0.05.

**TABLE 1.** Mean ± SD for variables obtained during the incremental lactate test.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
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<tbody>
<tr>
<td>W_peak (W)</td>
<td>358.3 ± 15.6</td>
</tr>
<tr>
<td>W_OBLA (W)</td>
<td>285.7 ± 32.3</td>
</tr>
<tr>
<td>W_LTlog (W)</td>
<td>281.6 ± 24.2</td>
</tr>
<tr>
<td>W_20-min (W)</td>
<td>247.6 ± 37.1</td>
</tr>
</tbody>
</table>

**RESULTS**

The mean (± SD) VO_2max of the cyclists were 4.85 ± 0.3 L·min⁻¹ and 62.7 ± 4.8 mL·kg⁻¹·min⁻¹, respectively. The physiological variables obtained in the incremental lactate tests are shown in Table 1. The average power output (in watts) in the 20-min TT and the 90-min TT was 323.7 ± 17.2 and 284.3 ± 8.6, respectively. Figure 1 demonstrates the average power output (in watts) during the 90-min (W_90-min) and 20-min (W_20-min) TT as a percentage of W_peak. The W_20-min and W_90-min during the TT was significantly (P < 0.01) different. Furthermore, W_20-min was not correlated (r = 0.66, P = 0.54) to W_90-min. Correlation coefficients between each physiological variable obtained from the incremental exercise testing, W_90-min and W_20-min are shown in Table 2. Figure 2 graphically demonstrates the relationship between W_peak and W_90-min.

**DISCUSSION**

Previous studies have shown the W_peak obtained during an incremental cycle test to exhaustion is a valid and reliable indicator of endurance cycle performance (3,17). However, this study was conducted to examine whether this variable correlated with cycle TT performance over durations of 20 min or 90 min. The cyclists in this study were not elite and included non-elite 'recreational' cyclists.

**TABLE 2.** Correlation coefficients between each variable obtained from the ramp as well as incremental lactate tests and average power output during the 90-min (W_90-min) and 20-min (W_20-min) TT.

<table>
<thead>
<tr>
<th>Variable</th>
<th>W_20-min</th>
<th>W_90-min</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO_2max (L·min⁻¹)</td>
<td>0.69*</td>
<td>0.38</td>
</tr>
<tr>
<td>VO_2max (mL·kg⁻¹·min⁻¹)</td>
<td>0.47</td>
<td>0.11</td>
</tr>
<tr>
<td>W_peak (W)</td>
<td>0.54</td>
<td>0.91**</td>
</tr>
<tr>
<td>W_LTlog (W)</td>
<td>0.67*</td>
<td>0.91**</td>
</tr>
<tr>
<td>W_OBLA (W)</td>
<td>0.23</td>
<td>0.54</td>
</tr>
<tr>
<td>D_max (W)</td>
<td>0.45</td>
<td>0.77*</td>
</tr>
</tbody>
</table>

VO_2max: maximum oxygen uptake obtained in the ramp test; W_peak: maximum power output obtained in the lactate test; W_LTlog: power output when blood lactate increases when log ([La⁺]) is plotted against log (W); W_OBLA: power output at a blood lactate concentration of 4 mmol·L⁻¹; D_max, the lactate threshold as determined by the D_max method.

* P < 0.05; ** P < 0.01.
the D max lactate threshold. In contrast, 20-min TT perfor-
performance was highly related to Wpeak, WLTlog, and
(10,23,25). The results of the study demonstrate that 90-min
work is needed to examine the reliability and validity of
calculate the relationship between these sets of variables. Further
training studies, high correlation coefficients have been
reported between the maximum workload and the time (in
minutes) (r = −0.91) or average speed (in km·h⁻¹) (r = 0.83) during a 40-km cycle TT (29,30). It has been recently
reported that the relationship between maximum workload and
TT performance is reduced when the time taken to
to complete a set distance is utilized (3). It is also likely that the
shorter duration incremental protocol used in the studies by
Weston et al. (30) and Westgarth-Taylor et al. (29) may
have resulted in a higher maximum power output than that
obtained in the current study. Unpublished data from this
laboratory demonstrates that the maximum workload during a shorter ramp test to exhaustion is not related to cycle TT
performance. Thus, the incremental exercise protocol used
to determine Wpeak together with performance measure (i.e.,
average speed, power output, or elapsed time) may influ-
ence the relationship between these sets of variables. Further
work is needed to examine the reliability and validity of
Wpeak obtained during different incremental exercise proto-
cols and the relationship to endurance performance differing
by mode and duration.

The average power output sustained by the cyclists in this
study during the 90-min TT was not related to the average
power output during the 20-min TT. As exercise intensity
inches above the LT, the utilization of glycogen for
energy metabolism is elevated (28). The average power
output during the 20-min TT approached 90% of Wpeak,
which is higher than the workload at the WLTlog and the
average power output during the 90-min TT. Therefore, it is
likely that accumulation of lactic acid was much greater
during the 20-min TT than in the 90-min TT. Thus, power
output decrement during the shorter duration TT may have
been influenced to a greater extent by metabolic acidosis
rather than substrate depletion. In contrast to shorter dura-
tion endurance exercise, previous studies have also shown
that during endurance exercise lasting more than 60 min the
utilization of free fatty acids (FFA) and triglycerides in-
creases (21,22). It is also well known that endurance training
enhances the capacity of skeletal muscle to utilize FFA, thus
delaying the reduction in work output as a consequence of
glycogen depletion (19). From the data presented in these
studies, it is possible that substrate depletion may have been
more influential during the 90-min TT as opposed to a
disruption of the contraction process by metabolic acidosis
(1) during the 20-min TT. This aside, other studies have
quantified the exercise intensity during cycle TT in using
heart rates coupled with incremental exercise test results
(25). These studies suggest that elite cyclists spend a greater
portion of the exercise time above the LT in TT lasting
60-min, which would result in substantial accumulation of
blood lactate. The findings of the present study suggest that
heightened adaptation of processes effecting lactate metab-
olism such as acid-base balance or FFA metabolism may be
more influential during the 20-min or 90-min TT, respec-
tively. It is also very likely that the metabolic response to a
20-min and 90-min TT will be affected by the ability level
of the cyclists being tested.

It is common for the workload associated with set lactate
values (i.e., the OBLA), inflection points, or mathematical
models such as the Dmax lactate threshold to be used to
assess endurance athletes (7,8). The results demonstrate that
WLTlog was related to both 20-min and 90-min TT perfor-
mances. However, only 45% of the variation in W20-min was
explained by WLTlog in contrast to 83% for W90-min. The
Dmax lactate threshold was also highly related to 90-min (r²
= 0.59) but not 20-min TT performance (r² = 0.20). How-
ever, the WOBLA was not related to either 20-min or 90-min
TT performance.

Theoretically, athletes with an elevated power output at the
LT may exercise at a higher work rate without accumu-
lation of blood lactate compared with those with a lower
power output at the LT. The LT is also known to be related
to muscle oxidative capacity (20), and this is thought to be
one factor that positively influences FFA metabolism during
prolonged submaximal exercise (11,15). Therefore, it is
likely that these characteristics associated with the WLTlog
partly explained the high correlation of this variable to
W90-min. However, the fact that only 45% of the variation in
W20-min was explained by WLTlog seems to indicate that
other factors aside from the ability to delay lactate accumu-
lation during incremental exercise may reflect short TT
performance.

FIGURE 2—The relationship between maximum power output
(Wpeak) and mean power output during the 90-min TT (W90-min).
In contrast to other investigations (8,27), the present results show that W_{OBLA} was not related to either the average power output during the 20-min or 90-min TT. One difficulty that has been reported in using the workload at set blood lactate concentrations is the extreme variability in lactate diffusion from muscle into the blood (24). Other factors associated with lactate transportation and elimination from the exercising muscle may influence the blood lactate concentration during incremental exercise (9). Therefore, it is possible the W_{OBLA} may not be a reflection of the muscle metabolic stress that occurred at the workload eliciting the set lactate concentrations.

Hawley et al. (16) suggested that endurance events are those that encompass a duration of greater than 20 min.

REFERENCES


Address for correspondence: David J. Bentley, Department of Sport and Exercise Science, University of Bath, Bath BA2 7AY, United Kingdom; E-mail: sppdbj@bath.ac.uk.