Physiological Correlations With Short, Medium, and Long Cycling Time-Trial Performance

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Physiological Correlations With Short, Medium, and Long Cycling Time-Trial Performance

Fernando K. Borszcz, Artur F. Tramontin, Kristopher M. de Souza, Lorival J. Carminatti, and Vitor P. Costa

1Santa Catarina State University; 2Federal University of Santa Catarina

ABSTRACT

Purpose: Several studies have demonstrated that physiological variables predict cycling endurance performance. However, it is still unclear whether the predictors will change over different performance durations. The aim of this study was to assess the correlations between physiological variables and cycling time trials with different durations. Methods: Twenty trained male cyclists (maximal oxygen uptake [VO2max] = 60.5 ± 5.6 mL/kg/min) performed 4 separate experimental trials during a 2-week period. Cyclists initially completed an incremental exercise test until volitional exhaustion followed by 3 maximal cycling time trials on separate days. Each time trial consisted of 3 different durations: 5 min, 20 min, and 60 min performed in a randomized order. Results: The main results showed that the physiological measures strongly correlated with long cycling performances rather than short and medium time trials. The time-trial mean power output was moderately high to highly correlated with peak power output and VO2max (r = .61–.87, r = .72–.89, respectively), and was moderately to highly correlated with the lactate threshold Dmax method and second ventilatory threshold (r = .52–.75, r = .55–.82, respectively). Conclusions: Therefore, trained cyclists should develop maximal aerobic power irrespective of the duration of time trial, as well as enhancements in metabolic thresholds for long-duration time trials.

In cycling time-trial (TT) competitions, athletes cover a fixed distance in a minimum time possible. Individual TT competitions are performed in a short distance of about 5 km, a medium distance of about 20 km, and a long distance of about 60 km (Atkinson, Peacock, St Clair Gibson, & Tucker, 2007). One of the key factors that the coach must understand to prescribe an effective training program is the physiological determinants of cycling performance. In this regard, scientific literature has shown that peak power output (PPO) and power at lactate/ventilatory thresholds (LT, VT) are the physiological predictors of cycling TT performance (Aman, Subudhi, & Foster, 2004, 2006; Balmer, Davison, & Bird, 2000; Bentley, McNaughton, Thompson, Vleck, & Batterham, 2001; Hawley & Noakes, 1992; Hopkins & McKenzie, 1994). A previous study showed that PPO was significantly and highly correlated with long endurance during a 90-min TT (r = .91, p < .01) and was moderately correlated with the shortest duration performance (20-min TT, r = .54, p < .01; Bentley et al., 2001). In fact, several other studies have shown that PPO predicts different cycling performance distances. Peak power output was highly correlated with a 20-km TT (r = −.91) and 40-km TT (r = −.87) and was moderately highly correlated with a 100-km TT (r = .64), respectively (Bentley, Wilson, Davie, & Zhou, 1998; Hawley & Noakes, 1992; Levin, Laursen, & Abbiss, 2014). In long TT competitions, cycling performance is partly determined by the ability of the cyclist to sustain high power outputs similar to the intensity that elicits LT/VT. Early studies have shown that VT was highly correlated with 40-km TT performance (r = .81; S. R. Hopkins & McKenzie, 1994). More recently, Levin et al. (2014) found that second ventilatory threshold (VT2) was moderately high and significantly correlated with a 30-km TT (r = .74, p < .01) and moderately but not statistically significantly correlated with long endurance performance (100-km TT, r = .49, p = .178). Therefore, power output at metabolic thresholds is probably more important for moderate and long TT performances.

Indeed, several studies have revealed that LT/VT and PPO predict different lengths of cycling TT performances (Aman, 2004, 2006; Balmer et al., 2000; Bentley et al., 2001; Hawley & Noakes, 1992; S. R. 2018 SHAPE America
Hopkins & MacKenzie, 1994). Studies investigating the relationship between power output at the LT/VT and PPO with short, medium, and long cycling TT were not found and could provide important insights showing that predictors may change depending on the length of the TT completed. In addition, training programs to develop each determinant of endurance performance can be influenced by the strength of the association with cycling performance. Thus, the objective of this study was to correlate the physiological variables of maximal oxygen uptake (VO$_2$max), PPO, LT and VT, and economy (EC) with 5-min, 20-min, and 60-min cycling TT in trained cyclists.

**Methods**

**Experimental approach to the problem**

To investigate the relationship between physiological variables with 5-min, 20-min, and 60-min cycling TT in trained cyclists, an incremental exercise test and different duration TT were carried out in the laboratory conditions. The three different TT were chosen due to their similarity with cycling events—for example, the 4,000-m races on the track (~5 min; Jeukendrup, Craig, & Hawley, 2000; Stone, Thomas, Wilkinson, St Clair Gibson, & Thompson, 2011), the prologues in the 3-week Grand Tour events, which usually are performed up to 16 km (~20 min; Balmer et al., 2000), and the traditional 1-hr world record (60 min). To this purpose, 20 trained male cyclists participated in four different sessions. In the first session, the cyclists performed an incremental exercise test. In the second, third, and fourth sessions, cyclists performed a self-paced TT in a randomized order.

**Participants**

Twenty trained male cyclists ($M_{\text{age}} = 33.6 \pm 6$ years, range = 19–51 years; $M_{\text{weight}} = 76.9 \pm 8.7$ kg; $M_{\text{height}} = 179 \pm 5.6$ cm) volunteered to participate in this study. All participants had 2 years of competition experience and were classified as trained (De Paw et al., 2013). The institutional human research ethics committee approved the study. Cyclists were previously informed of the risks of the study and gave their written informed consent before participating.

**Procedures**

Participants reported to the laboratory on 4 separate days during a period of 2 weeks. Initially, participants completed a graded exercise test to volitional exhaustion to determine their physiological measures. Following the initial test, participants completed three different TT (i.e., 5 min, 20 min, 60 min) in a randomized order separated by at least 72 hr. All the tests were conducted on an electronically braked cycle ergometer (Velotron Dynafit Pro, RacerMate, Seattle, WA); the measurement error associated with Velotron in constant power trials is <1% (Abbiss, Quod, Levin, Martin, & Laursen, 2009). Throughout all tests, the ambient temperature of the laboratory was controlled at ~21°C with a relative humidity of ~54%.

**Incremental exercise test**

Participants completed an incremental exercise test to volitional exhaustion to determine PPO, VO$_2$max, metabolic thresholds, and EC. Participants initially began exercising at 100 W and increased by 40 W every 4 min thereafter until reaching volitional exhaustion. During the test, respiratory gases were continuously measured by breath with a metabolic cart (Quark PFTergo, Cosmed, Rome, Italy) calibrated in accordance with manufacturer instruction. Heart rate (HR) measurements were recorded using an HR strap registered by the gas analyzer. Capillary blood samples were obtained from the earlobe during the last seconds of each stage and were immediately analyzed (YSI 1500, Yellow Springs, OH). Peak power output was determined according to Kuipers, Verstappen, Keizer, Geurten, and Van Kranenburg (1985), and VO$_2$max was considered to be the highest average 30 s of oxygen uptake. The first lactate threshold was determined by the following methods: (a) 2 mmol/L, power output fixed at lactate concentration in 2 mmol/L (Kirdermann, Simon, & Keul, 1979); and (b) baseline + 1 mmol/L, the point where the level of lactate in the blood rises by 1 mmol/L over exercise baseline (Coyle, 1995). The second lactate threshold was determined by the following methods: (a) Dmax, the point on the regression curve that yields the maximal distance to the straight line formed by the two end points of the curve (Cheng et al., 1992); and (b) onset of blood lactate accumulation (OBLA), or power output fixed at lactate concentration in 4 mmol/L (Heck et al., 1985). The first and second ventilatory thresholds (VT$_1$, VT$_2$, respectively) were determined according to Lucia, Hoyos, Pérez, and Chicharro (2000): (a) VT$_1$ occurred with augments in the equivalent ventilation/oxygen uptake (VE/VO$_2$) and partial pressure of oxygen without any increase in the equivalent ventilation/carbon dioxide production (VE/VCO$_2$); and (b) VT$_2$ occurred with augments in VE/VO$_2$ and VE/VCO$_2$ and a decrease in partial pressure of carbon dioxide. Economy was determined using the relation power output/VO$_2$ at a fixed power of 180 W during the incremental test. The EC calculation was considered the average VO$_2$ of the
last minute at the 180-W stage, and for all participants, the respiratory quotient was < 1.0 at 180 W.

**Time trials**

All participants completed three TT in the laboratory using the Velotron cycle ergometer. The Velotron allowed the cyclists to manually shift the gears attached on the handle bar while pedaling. For each test, the Velotron was positioned in front of a computer-generated image of the three-dimensional course profile in front of the cyclist. The screen in front of the cyclist gives information on current speed, power, cadence, HR, draft, distance, and time. In our study, we blinded the main variables to prevent pacing strategy except for time completed and gear selections. In addition, we did not provide any verbal encouragement.

Participants initially completed a 20-min standardized warm-up consisting of three repeated increasing-intensity bouts. The first 2 min were completed at 2 W/kg to 2.5 W/kg, followed by 2 min at 3 W/kg to 3.5 W/kg, and finally 1 min at 4 W/kg to 4.5 W/kg and repeated consecutively. For the final 5 min, participants pedaled at a fixed intensity of 100 W. Thereafter, a 5-min, 20-min, or 60-min self-paced maximal TT was performed in a randomized order separated by at least 72 hr. The TT were completed on a designed flat course, and participants were permitted to consume water ad libitum.

The Maximal values presented in Table 1 were calculated using the Pearson correlation coefficient (r) derived from log-transformed data (W. G. Hopkins, 2015). The correlations were interpreted according to the absolute criteria: < .19 = no correlation; .20 to .39 = low; .40 to .59 = moderate; .60 to .79 = moderately high; and ≥ .80 = high (Zhu, 2012). Standardized effect size (ES) is reported as Cohen’s d and is interpreted based on guidelines provided by W. G. Hopkins, Marshall, Batterham, and Hanin (2009): 0 to 0.19 = trivial; 0.20 to 0.59 = small; 0.6 to 1.19 = moderate; 1.20 to 1.99 = large; ≥ 2 = very large. Analyses were performed using SPSS statistical package (Version 21.0, IBM, Armonk, NY). Statistical significance was accepted at p < .05.

**Statistical analysis**

Descriptive statistics are presented as means (± SD). One-way analysis of variance with repeated measures was used to calculate the mean comparisons between the physiological variables and mean power output and HR during the TT with subsequent Tukey post-hoc comparisons. The correlations between the incremental exercise measures and cycling performance were calculated using the Pearson correlation coefficient (r) derived from log-transformed data (W. G. Hopkins, 2015). The correlations were interpreted according to the absolute criteria: < .19 = no correlation; .20 to .39 = low; .40 to .59 = moderate; .60 to .79 = moderately high; and ≥ .80 = high (Zhu, 2012). Standardized effect size (ES) is reported as Cohen’s d and is interpreted based on guidelines provided by W. G. Hopkins, Marshall, Batterham, and Hanin (2009): 0 to 0.19 = trivial; 0.20 to 0.59 = small; 0.6 to 1.19 = moderate; 1.20 to 1.99 = large; ≥ 2 = very large. Analyses were performed using SPSS statistical package (Version 21.0, IBM, Armonk, NY). Statistical significance was accepted at p < .05.

**Results**

The maximal and submaximal measurements from the incremental exercise test and the performance tests are presented in Table 1. The results showed that OBLA was significantly higher than all other metabolic thresholds (p < .05), with a moderate to very large ES (d = 0.8–3.2). In contrast, VT1 was significantly lower than all other metabolic thresholds (p < .01), with a large to very large ES (d = 1.5–3.2). Dmax was statistically higher than baseline + 1 mmol/L and 2 mmol/L (p < .05), with a small and moderate ES (d = 0.5, 0.7).

<table>
<thead>
<tr>
<th>Table 1. Mean ± SD for variables obtained during the incremental exercise test and performance tests.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable</strong></td>
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<tr>
<td>-----------------</td>
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<tr>
<td><strong>Maximal values</strong></td>
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<tr>
<td>PPO (W)</td>
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<tr>
<td>VO2max (L/min)</td>
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<tr>
<td>VO2max (mL/Kg/min)</td>
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<tr>
<td>HRmax (bpm)</td>
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<tr>
<td><strong>Submaximal values</strong></td>
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<tr>
<td>OBLA (W)</td>
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<tr>
<td>Dmax (W)</td>
</tr>
<tr>
<td>VO2max + 1 mmol/L (W)</td>
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<tr>
<td>VO2max + 2 mmol/L (W)</td>
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<tr>
<td>VT1 (W)</td>
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<tr>
<td>VT2 (W)</td>
</tr>
<tr>
<td>EC (W/L/min)</td>
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<tr>
<td><strong>Time trials</strong></td>
</tr>
<tr>
<td>5-min TT (W)</td>
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<tr>
<td>20-min TT (W)</td>
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<tr>
<td>60-min TT (W)</td>
</tr>
</tbody>
</table>

Note. PPO = peak power output; VO2max = maximal oxygen uptake; HRmax = maximal heart rate; Dmax = Dmax method; OBLA = onset blood lactate accumulation; VT1 = second ventilatory threshold; VT2 = first ventilatory threshold; EC = economy at 180 W; TT = time trial.

*Significantly different from 5-min TT.

*Significantly different from 20-min TT.

*Significantly different from 60-min TT.

*Significantly different from all other thresholds; ^Significantly different from Dmax and VT2. Significant differences at p < .05.
respectively, and it was not different from VT$_2$ ($p = .82$, $d = 0.3$). There was a trivial difference between baseline + 1 mmol/L and 2 mmol/L ($p = .74$, $d = 0.1$).

The main results of the performance tests were that the mean power output was significantly different between each test ($p < .05$), the ES between the 5-min and 20-min TT was moderate ($d = 1.1$), the ES between the 5-min and 60-min TT was large ($d = 1.8$), and the ES between the 20-min and 60-min TT was moderate ($d = 0.6$). In addition, PPO was statistically higher than all the performance tests, with an ES of $d = 0.8$ to $d = 2.8$. The difference between OBLA and the 20-min TT was small ($d = 0.3$) and not significant ($p = .65$); and the difference between between 60-min TT with Dmax and VT$_2$ was trivial to small and not significant ($p = .58$, $d = 0.1$; $p = .31$, $d = 0.2$, respectively).

Table 2 shows the correlations between physiological measures and cycling TT performances with different distance length. The main results showed that TT mean power output was significantly and moderately to highly correlated with PPO ($r = .72$–.89), VO$_2$max ($r = .61$–.87), Dmax ($r = .52$–.75), and VT$_2$ ($r = .55$–.82). In addition, the physiological measures were highly correlated for long TT rather than short and medium TT.

**Table 2. Pearson’s correlations between physiological measures and cycling time-trial performances.**

<table>
<thead>
<tr>
<th></th>
<th>VO$_2$max (L/min)</th>
<th>Dmax (W)</th>
<th>OBLA (W)</th>
<th>2 mmol/L (W)</th>
<th>Baseline + 1 mmol/L (W)</th>
<th>VT$_2$ (W)</th>
<th>VT$_1$ (W)</th>
<th>EC (W/L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-min TT (W)</td>
<td>.72** .61* .58*</td>
<td>.32 .07</td>
<td>.09 .55</td>
<td>.39 −.49</td>
<td>−.54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-min TT (W)</td>
<td>.84** .79** .70*</td>
<td>.49 .25</td>
<td>.31 .67*</td>
<td>.61* −.54</td>
<td>−.54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60-min TT (W)</td>
<td>.89** .87** .75**</td>
<td>.56* .26</td>
<td>.31 .82*</td>
<td>.78** −.33</td>
<td>−.33</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. TT = time trial; PPO = peak power output; VO$_2$max = maximal oxygen uptake; Dmax = Dmax method; OBLA = onset blood lactate accumulation; VT$_2$ = second ventilatory threshold; VT$_1$ = first ventilatory threshold; EC = economy at 180 Watts; W = watts; L/min = liters per minute; W/L/min = watts per liters per minute.

* $p < .05$. ** $p < .01$.

Discussion

The aim of this study was to verify the relationship between physiological variables with 5-min, 20-min, and 60-min cycling TT in trained cyclists. The main finding of this study was that the correlations between the incremental exercise test measures with cycling performances were dependent on the TT distance. In general, the correlations between PPO, VO$_2$max, metabolic thresholds, and EC with 5-min TT were moderate and lower than the medium and long TT. In addition, the PPO, VO$_2$max, Dmax, and VT$_2$ were highly associated with long cycling TT performance.

It has been reported that time to exhaustion (TTE) at PPO was 240 ± 57 s in well-trained cyclists (Laursen, Shing, & Jenkins, 2003) and 230 ± 32 s in competitive cyclists (Costa, Matos, Pertence, Martins, & Lima, 2011). In this regard, PPO would be a determinant to enhance 5-min TT performance. In fact, the results of this study showed that PPO was better correlated to 5-min TT than the other physiological measures (Table 2). In addition, it is interesting to note that PPO was not only associated with short endurance performances. Actually, the PPO was more associated with long endurance performance than with moderate and short TT (Table 2). Accordingly, Bentley et al. (2001) found that the predictive capability of the PPO to associate with cycling performance was dependent on the length of the TT in a more homogeneous group of well-trained cyclists. The authors found that PPO highly and significantly correlated with mean power output during a 90-min TT ($r = .91$, $p < .01$) and was moderately associated with 20-min TT ($r = .54$, $p < .01$). In fact, several studies have presented moderately high to high associations with PPO and different performance durations such as 4-min TT ($r = .84$), 20-min TT ($r = .82$), 20-km TT ($r = .91$), 30-km TT ($r = .83$), 40-km TT ($r = .90$), and 100-km TT ($r = .64$; Clark, Paton, & O’Brien, 2015; Lamberts, Lambert, Swart, & Noakes, 2012; Levin et al., 2014; Nimmerrichter, Williams, Bachl, & Eston, 2010). Therefore, based on these studies, it seems that PPO is highly associated with cycling TT in spite of the course distance.

The LT and VT are based on the assumption of a causal relationship between lactate production and increased ventilation during incremental exercise. They have been used to determine the metabolic training zones, where: (a) Zone 1 corresponds to the intensity below the first LT/VT threshold, (b) Zone 2 corresponds to the intensity between the first and second LT/VT thresholds, and (c) Zone 3 corresponds to the intensities above the second LT/VT threshold (Seiler, 2010). The several methods of LT and VT determination led to statistically significant correlations with variable strength with different TT performance durations in cycling ranging from $r = .73$ to $r = .92$ (Amann et al., 2004, 2006). During TTE exercise, cyclists maintain the intensity at first LT and VT for a period of 2 hr to 3 hr (Coyle, 1995) and the intensity at second LT and VT during 30 min to 60 min (Faude, Kindermann, & Meyer, 2009).
Accordingly, Levin et al. (2014) also reported a higher correlation between VT2 and 30-km TT ($r = .74, p < .01$) compared with the 100-km TT ($r = .49, p < .178$). In addition, the authors found a low relationship between VT1 with 100-km TT ($r = .13, p = .744$). In general, the results of our study showed that the methods that represent the first LT and VT (i.e., 2 mmol/L, baseline + 1 mmol/L, and VT1) were less associated with the 5-min, 20-min, and 60-min TT than the second LT and VT (i.e., Dmax, VT2). Also, the correlations were higher and statistically significant for Dmax ($r = .75$) and VT2 ($r = .82$) for the 60-min TT compared with the 5-min TT ($r = .54$, $r = .55$, respectively). Moreover, power output at Dmax ($237 \pm 38$ W) and VT2 ($226 \pm 48$ W) was not significantly different than that at 60-min TT ($235 \pm 33$ W). A likely reason for the lower correlations between the methods that represent the first LT and VT with cycling performance in our study is the duration of the performance tests. These methods are more related to long endurance performance where the acidosis levels are less pronounced and cyclists can sustain the power output for a prolonged period of time according to TTE at first LT or VT (Faude et al., 2009). Therefore, the second LT and VT correlations with endurance performance improved as the distances approached 60-min exercise. Our findings also help coaches and athletes who do not have access to laboratories and thus can use the 60-min TT as an indirect reference of the second metabolic threshold.

Early studies showed no correlation to a moderate correlation between cycling gross efficiency or delta efficiency with 20-min TT ($r = -.06, r = .09$, respectively) and 90-min TT ($r = .00$, $r = -.45$, respectively) (Bentley, Vleck, & Millet, 2005). Recently, Levin et al. (2014) reported no correlation to low and non-statistically significant correlations between EC and 30-km TT ($r = .18, p = .492$) and 100-km TT ($r = .30, p = .435$). In contrast, in our study, there were moderate correlations between cycling EC and TT performance durations ($r = -.49, r = -.54, r = -.53$, respectively). These later results are in accordance with a more recent study that showed a moderately high correlation between cycling gross efficiency and TT performance time ($r = -.70$; Clark et al., 2015). Cycling EC or efficiency is considered an important determinant of endurance performance (Joyner & Coyle, 2008). Also, there are different methods of training such as high-intensity interval training and strength training to develop cycling EC or efficiency. In addition, there are EC or efficiency changes throughout the annual competitive cycling season (Hopker, Coleman, & Passfield, 2009). Thus, measures of EC or efficiency should be included during testing procedures throughout the annual competitive cycling season.

**Conclusions**

In summary, the main finding from our study was that the strength of and the achievement of statistical significance of correlations between the PPO, VO2max, metabolic thresholds, and EC with cycling performances were dependent on TT duration. In general, the correlations between PPO, VO2max, metabolic thresholds, and EC and performance were higher for the long TT.

**What does this article add?**

Endurance performance is determined by a combination of high values of VO2max, metabolic thresholds, and EC. The practical applications of the study suggest that trained cyclists should develop maximal aerobic power output due its association with endurance performance irrespective of distance. Trained cyclists should also enhance LT/VT power output to better perform medium and long endurance performance. Although EC may be less important for short events, as the length of the performance increases, EC is a determinant for endurance performance.

**ORCID**

Fernando K. Borszcz [http://orcid.org/0000-0002-3773-6906]
Artur F. Tramontin [http://orcid.org/0000-0002-2084-5137]
Vitor P. Costa [http://orcid.org/0000-0001-9146-6858]

**References**


