Prediction of Drafted-Triathlon Race Time From Submaximal Laboratory Testing in Elite Triathletes

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Catalogue Data

Key words: swimming, cycling, running, lactate, oxygen uptake
Mots-clés: natation, bicyclette, course, lactates, consommation d’oxygène

Abstract/Résumé

Purpose and methods: To determine which physiological variables accurately predict the race time of an Olympic-distance International Triathlon undertaken in drafted conditions, 8 elite triathletes underwent both maximal and submaximal laboratory and field physiological testing: a 400-m maximal swim test; an incremental treadmill test; an incremental cycling test; 30 min of cycling followed by 20 min of running (C-R); and 20 min of control running (R) at the exact same speed variations as in running in C-R. Blood samples were drawn to measure venous lactate concentration after the 400-m swim and the cycle and run segments of C-R. During the maximal cycling and running exercises, data were collected using an automated breath-by-breath system. Results: The only parameters correlated with the overall drafted-triathlon time were lactate concentration noted at the end of the cycle segment (r = 0.83, p < 0.05) and the distance covered during the running part of the submaximal C-R test (r = −0.92, p < 0.01). Stepwise multiple regression analysis revealed a highly significant (r = 0.96, p < 0.02) relationship between predicted race time (from laboratory measures) and actual race time, using the following calculation: Predicted Triathlon Time (s) = −1.128 (distance covered during R of C-R [m]) + 38.8 ([lactate] at the end of C in C-R) + 13,338. The high R² value of 0.93 indicated that, taken together, these two laboratory measures could account for 93% of the variance in race times during a drafted triathlon. Conclusion: Complementing previous studies, this study demonstrates

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that different parameters seem to be reliable for predicting performance in drafted vs. nondrafted Olympic-triathlon races. It also demonstrates that, for elite triathletes competing in a drafted Olympic-distance triathlon, performance is accurately predicted from the results of submaximal laboratory measures.

But et méthodes: Le but de cette étude est d’identifier les variables physiologiques qui indiquent avec justesse le temps de performance d’un triathlon de calibre olympique réalisé en peloton. Huit triathlons d’élite participent à des épreuves sous-maximales et maximales en laboratoire et sur le terrain: vitesse de nage sur 400 m; test progressif sur tapis roulant; test progressif sur bicyclette; 30 min de course à bicyclette suivi de 20 min de course à pied (C-R); et 20 min de course comme variable de contrôle (R) exécutée en suivant les mêmes variations de vitesse qu’à la course en C-R. Des échantillons de sang veineux sont prélevés pour l’analyse de la concentration de lactates après l’épreuve de nage, de bicyclette, et des portions de course dans C-R. Au cours des épreuves maximales sur bicyclette et à la course, l’analyse des gaz est faite, à chaque respiration, à l’aide d’un système automatisé. Résultats: Les seules variables associées au temps de performance globale en peloton sont la concentration de lactates observée à la fin de la portion à bicyclette (r = 0,83, p < 0,05) et la distance franchie à la course dans les tests sous-maximaux C-R (r = −0,92, p < 0,01). L’analyse de régression par palier montre une très forte corrélation (r = 0,96, p < 0,02) entre le temps prédit d’après les mesures en laboratoire et le temps de performance sur le terrain: Temps de performance (s) prédit au triathlon = –1,128 (distance franchie en R de C-R [m]) + 38,8 ([lactates] à la fin de C dans C-R) + 13 338. Le coefficient de détermination de 0,93 indique que les deux mesures de laboratoire expliquent à elles seules 93% de la variance du temps de performance dans un triathlon réalisé en peloton. Conclusion: d’après la nature des variables de laboratoire prédictives du temps de performance dans un triathlon olympique, il y a lieu de porter une attention particulière à l’efficacité à bicyclette et à la performance à la course. Par conséquent, les athlètes et les entraîneurs doivent cibler (a) la stratégie de course à bicyclette pour garder basse la concentration de lactates, et (b) l’amélioration de la performance maximale à la course à pied.

Introduction

The physiological demands of the triathlon and the physiological profiles of triathletes have been comprehensively reviewed (Basset and Boulay, 2000; Hue et al., 2000a; O’Toole and Douglas, 1995). The physical and physiological factors or predictors of success in the Olympic-distance triathlon have been studied in both male and female recreational triathletes (Butts et al., 1991; Laurenson et al., 1993; Miura et al., 1997) and elite triathletes (Laurenson et al., 1993; Schabort et al., 2000). High \( \bar{V}O_2 \)max levels and a high anaerobic threshold are required for success (Sleivert and Rowlands, 1996; Sleivert and Wenger, 1993). Although \( \bar{V}O_2 \)max is thus a predictor of performance in triathletes of mixed abilities (Butts et al., 1991), Sleivert and Rowlands (1996) demonstrated that it could not be used to predict performance in homogeneous groups of elite performers. The most relevant predictor of performance in groups of well-trained or elite male performers seems to be the oxygen-uptake (\( \bar{V}O_2 \)) at running ventilatory threshold (Sleivert and Wenger, 1993). Recently, Schabort et al. (2000) showed that the race time for top triathletes competing in the Olympic-distance race could be accurately predicted from the results of maximal and submaximal laboratory measures. To the
best of our knowledge, this study was the first attempt to predict the overall performance times of nationally-ranked Olympic-distance triathletes by using physiological test results.

Although earlier studies that attempted to predict overall performance in Olympic-distance triathlons were conducted in nondrafting conditions, the Olympic race, as well as the Olympic-distance World Championship and world-class short distance races, now allows drafting, or the formation of clusters of riders in the cycling segment of the race. This allows triathletes to save a significant amount of energy and thus improve their running capabilities. In a recent study characterising the impact of drafting, Hausswirth et al. (1999) indicated that this new legalisation and the now-standard use of drafting in triathlon races has resulted in physiological and biomechanical alterations that can have an impact on performance, thus affecting the correlation between testing and performance.

The aim of the present study was to determine whether any of the physiological variables measured during laboratory testing could accurately predict the race times of elite triathletes taking part in an Olympic-distance triathlon in drafting conditions.

**Materials and Methods**

**SUBJECTS**

Eight male triathletes participated in this study. All were elite triathletes who had been chosen to represent France in a Triathlon Union World Championship within the 2 years preceding the study. They had been competing in the Triathlon for 6.2 years (± 2.1 yrs) and were in the competitive period at the time of the study. They were preparing to compete in the La Grande Motte International Triathlon, a drafted Olympic-distance race that is held at sea level on a flat out-and-back course and consists of a 1500-m sea swim, a 40-km cycle segment, and a 10-km run. The weather conditions during the race were 18.1 °C and 58% humidity, with a wind speed of 2.1 m·s⁻¹. Anthropometric data are reported in Table 1. All subjects were informed of the purpose of the study and gave written consent in accordance with the regional ethics committee before participating.

**Anthropometric Measurements.** After measurement of height and body mass, body fat content was estimated from the skinfold thickness (ST) expressed in millimeters. Four skin areas (biceps, triceps, subscapula, and suprailiac) were measured on the right side of the body with Holtain calipers, following the method described by Durnin and Rahaman (1967). The equation of Durnin and Rahaman was used to determine the percentage of body fat mass (BFM). Lean body mass (LBM) was determined from body mass and BFM. Buoyancy was evaluated by measurement of hydrostatic lift (HL, Chatard et al., 1995). HL corresponds to the force that enables swimmers to float when they are immersed during forced inspiration. It was measured at the end of a maximal inspiration when subjects were floating. The subject was in the fetal position facing downward. A lead mass, varying from 0.1 to 1 kg, was applied to the back at the level of the shoulder blades. The final load needed to maintain the subject in a balanced position just under water was considered to be the HL. This method has been shown to be highly reliable (r = 0.98 for 8 swimmers) and easy to use (Chatard et al., 1995).
Swim Performance. After a 15-min warm-up, performance was measured in a 50-m pool, with each swimmer starting in the water without diving. Water temperature was 26 to 26.5 °C. The subjects swam 400 m at a maximal velocity in this condition.

Stroke Frequency, Stroke Length, and Stroke Index. During the 400-m swims, subjects were instructed to keep as steady a pace as possible. The stroke frequency, expressed as the number of complete arm cycles·min⁻¹, was measured for each 50 m with a frequency meter on three complete stroke cycles, four times per 50 m. A mean value was retained for each 50 m. The stroke length (SL) was calculated by dividing the mean velocity of each 50-m length by the mean stroke frequency of the 50 m. The stroke index (SI) was calculated by dividing the mean swim square by the stroke frequency (Costill et al., 1985). This index assumes that, at a given velocity, the swimmer with the greatest stroke length has the most effective swimming technique and the most skill (Costill et al., 1985).

TESTING PROTOCOL

Each subject was tested in a 5-trial protocol that took place over 3 consecutive weeks and ended one week before the International Triathlon. The first 4 tests were randomised. The tests were conducted at the same time of day to minimise circadian effects, and on the same days of the week to minimise the effects of personal training on the results. The subjects were asked to maintain their training schedule throughout the study but were not allowed to compete in a triathlon during the testing period. All were familiarised with treadmill running and with the use of the cycle ergometer prior to testing. They were asked to refrain from training on experiment days. Trial 1 consisted of a 400-m maximal swim test; Trial 2

Table 1  Physical Characteristics, Training Regimen, and Results of La Grande-Motte Triathlon (classic distance) for 8 Elite Male Triathletes (mean ± SD)

<table>
<thead>
<tr>
<th>Physical Characteristics</th>
<th>24.7 ± 2.1</th>
<th>180.5 ± 9.3</th>
<th>71.4 ± 7.3</th>
<th>22.3 ± 0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
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<tr>
<td>Height (cm)</td>
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<tr>
<td>Weight (kg)</td>
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<td></td>
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<tr>
<td>Skinfold thickness (mm)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mean Training Distances</td>
<td></td>
<td>18.2 ± 4.6</td>
<td>331.2 ± 90.1</td>
<td>58.1 ± 14.5</td>
</tr>
<tr>
<td>(km-wk⁻¹)</td>
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<td></td>
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</tr>
<tr>
<td>Swim</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Bike</td>
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</tr>
<tr>
<td>Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>La Grande-Motte Triathlon</td>
<td></td>
<td>1:44:02 – 1:53:16</td>
<td>4 – 45</td>
<td></td>
</tr>
<tr>
<td>Time (range, h:min:s)</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Place (range)</td>
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</table>

Note: Training distances were averaged during the study. Skinfold thickness taken from sum-of-4 site.
was an incremental treadmill test; Trial 3 was an incremental cycle test; Trial 4 (C-R) consisted of 30 min of cycling followed by 20 min of running; Trial 5 (R) involved 20 min of control running at the exact same speed variations as in running in C-R.

**Maximal Cycling and Running Tests.** The incremental cycle test was performed on an electromagnetic cycle ergometer (Monark 864, Monark-Crescent AB, Varburg, Sweden). After a 3-min warm-up at 30 W, the power was then increased by 30 W every minute until the subject reached volitional fatigue. Peak power output (PPO) was defined as the highest workload the subject could maintain for 60 s. When the exercise intensity could not be maintained for the full 60 s, PPO was calculated by adding the fraction of the last, uncompleted workload to the preceding completed work (Kuipers et al., 1985):

\[
PPO (W) = W_{\text{final}} + \frac{(t/60) \times 30}{3}
\]

where PPO is the peak sustained power output in W, \(W_{\text{final}}\) is the last exercise intensity in W the cyclist reached for 60 s, and t is the duration in seconds for which the final, uncompleted exercise intensity was sustained.

The incremental treadmill (Gymroll 1800, Gymroll, Roche La Molière, France) test began at 5 km·h\(^{-1}\) for one minute at 0% grade. The speed was then increased by 1 km·h\(^{-1}\) every minute up to a maximum speed of 18 km·h\(^{-1}\). The speed was then held constant and the grade was increased by 1% every minute until the subject reached exhaustion. The triathlete’s peak treadmill velocity was taken as the highest graded speed he maintained for 60 s as recorded by Margaria et al. (1963):

\[
\text{Peak treadmill speed} = \text{Speed} + \frac{(\% - 1.5)}{1.5}
\]

where Speed is the maximal velocity attained by the subject in km·h\(^{-1}\), \(\%\) is the grade attained at Speed, and 1.5 is the grade at which a rise of 1.5% corresponds to an increase of 1 km·h\(^{-1}\). For example, for a subject who attained 18 km·h\(^{-1}\) with a grade of 9%, the peak treadmill velocity was 18 + (9 – 1.5) / 1.5 = 23 km·h\(^{-1}\).

When a subject was unable to complete a full 60 s at required speed, peak treadmill running speed was determined as a fraction of the final graded speed added to the velocity of the immediately preceding completed graded speed.

**Submaximal Cycle-Run and Run Tests.** For the submaximal tests, the triathletes were instructed to perform as fast as possible. In Trial 4 they used their own cycles set on a home trainer (Cycletrack, Tacx, Aardenburg, Holland). The cycles were equipped with low profile handlebars. At the end of the 30 min of cycling, they had 1 minute to change their shoes and step onto the treadmill. This time corresponded approximately to the cycle-run change time in an official triathlon. The triathletes began the 20-min run at a speed calculated to be close to their performance level in a classic triathlon. This run speed was reached in less than 1 minute. The triathletes then adjusted their speed by 0.5 km·h\(^{-1}\) each minute in order to optimise performance. Trial 5 was performed at the exact same speed evolutions as those noted during Trial 4. Cycling distance was recorded using a bike odometer (Cateye Mity 2, Cateye, Osaka, Japan) and running distance was recorded using the treadmill odometer. The C-R test has already been described
and used in earlier studies to evaluate the physiological characteristics of the cycle-run succession (Hue et al., 1999; 2000b; 2000c).

The calculation of the energy cost for running and cycling was made using the formula given by Di Prampero (1986):

$$CE = \frac{[(\dot{V}O_2 - 0.083) / speed] \times 60}{360}$$

where CE is the energy cost of running or cycling (ml of O$_2$·min$^{-1}$·km$^{-1}$); $\dot{V}O_2$ (ml·kg$^{-1}$·min$^{-1}$) is the mean oxygen consumption during the submaximal test; speed (km·h$^{-1}$) is the mean speed during the test; and 0.083 (in ml·kg$^{-1}$·s$^{-1}$) is the value corresponding to the y-intercept of the $\dot{V}O_2$-speed relationship established in young men (Medbo et al., 1988).

GAS EXCHANGE MEASUREMENTS

Metabolic and cardiopulmonary data were measured every minute using a mass spectrometer breath-by-breath automated system (MGA-1100, Marquette, NY): minute ventilation ($\dot{V}E$), oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory equivalents for O$_2$ ($\dot{V}E/\dot{V}O_2$) and CO$_2$ ($\dot{V}E/\dot{V}CO_2$), respiratory exchange ratio (R), breathing frequency (f), and tidal volume ($V_T$). Heart rate (HR) was measured using a telemetry system (Polar Racer, Polar Electro, Kempele, Finland).

**Ventilatory and Respiratory Compensation Thresholds.** The ventilatory threshold (Th$\text{vent}$) was determined using the V-slope method of Beaver et al. (1986). This method involves the analysis of $\dot{V}CO_2$ as a function of $\dot{V}O_2$ and assumes that Th$\text{vent}$ corresponds to the break point in the $\dot{V}CO_2/\dot{V}O_2$ relationship. Similarly, the respiratory compensation threshold (RCT) corresponds to the work rate beyond which lactic acid begins to accumulate in the blood during exercise at a faster rate than it can be cleared, exhausting the buffering capacity of bicarbonate. RCT is characterised by the same ventilatory patterns as Th$\text{vent}$ with the addition of a marked increase in $\dot{V}E/\dot{V}CO_2$ (Préfaut and Mercier, 1993). The figure of these threshold determinations has been shown in a previous study (Hue et al., 2000a).

Both thresholds were automatically determined using a gas analyser and then verified independently by two experienced researchers.

POSTEXERCISE BLOOD LACTATE CONCENTRATION

**Swim Test.** Two blood samples were taken at a fingertip after the first minute following the 400-m swims. Lactate concentrations were measured with a blood lactate analyser (Accusport, Boehringer, Mannheim, Germany) that has been shown to be valid and reliable (Bishop, 2001; Wiggleworth et al., 1996).

**Cycle-Run and Run Tests.** A venous catheter was inserted in a superficial forearm vein before the C-R trial to allow sampling for measurement of lactate concentrations. A three-way tap was placed on the catheter to allow rinsing with a syringe containing a mixture of heparin (250 IU·ml$^{-1}$) and blood sampling with a dry syringe after the catheter had been cleared of saline. Approximately 3 ml of blood was sampled at rest (T0), after cycling (T1), and at the end of C-R (T2).
**Blood Lactate Analysis.** Approximately 3 ml of blood was placed in a tube (EDTA), centrifuged (3,000 rpm for 10 min), and stored at –18 °C for lactate analysis. The measurements were carried out with an enzymatic method without deproteinization (MPR 3 Lactate, Boehringer).

**Statistical Analysis.** All values are presented as mean ± standard deviation (SD). Pearson product-moment correlations describe, for all triathletes, the relationships between the individual physiological variables measured and race time in each phase of the triathlon, as well as for overall race time. A stepwise multiple linear regression was used to determine the best predictors of overall race time. For all statistics, a significance level of \( p < 0.05 \) was preset. When multiple linear regression improved the prediction of triathlon performance over simple correlation, care was taken to improve the accuracy of the independent variables by gauging the strength of the resultant \( R^2 \), which indicates the portion of the variance of performance explained by the independent variables.

**PARAMETERS TESTED**

The physiological parameters tested in the present study were those habitually tested in laboratory studies (see parameters listed in Tables 2, 3, and 4). A control run was added to the study because recent studies have demonstrated that the difference between (a) the energy cost of running after cycling vs. running alone (Millet et al., 2000) and (b) the minute ventilation of running after cycling vs. running alone (Hue et al., 1999; 2000b) are both important factors of performance discrimination in triathletes.

**Results**

Table 2 displays the overall race time along with the splits for each segment of the race. Tables 3 and 4 display maximal and submaximal variables recorded during maximal and submaximal tests. For these elite triathletes, the times for both the cycling and running segments were significantly correlated with total triathlon time (\( r = 0.87, p < 0.03 \), and \( r = 0.83, p < 0.04 \)). None of the maximal cycling or running variables, i.e., \( \dot{V}O_2 \) max, ventilatory and respiratory compensation thresh-

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swim (1500 m)</td>
<td>17:33</td>
<td>0:33</td>
<td>17:00 – 18:00</td>
</tr>
<tr>
<td>Cycle (40 km)</td>
<td>54:18</td>
<td>1:28</td>
<td>53:00 – 56:10</td>
</tr>
<tr>
<td>Run (10 km)</td>
<td>32:54</td>
<td>1:28</td>
<td>31:00 – 36:20</td>
</tr>
<tr>
<td>Overall time</td>
<td>1:46:58</td>
<td>0:03:26</td>
<td>1:44:02 – 1:53:16</td>
</tr>
<tr>
<td>Racing time</td>
<td>1:44:46</td>
<td>0:03:55</td>
<td>1:42:35 – 1:50:30</td>
</tr>
</tbody>
</table>
Table 3 Maximal Physiological Variables for 8 Elite Triathletes in 3 Events

<table>
<thead>
<tr>
<th>Variable</th>
<th>Swim</th>
<th>Cycle</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>400-m time (s)</td>
<td>288.3 ± 12.7</td>
<td>0.83 a</td>
<td></td>
</tr>
<tr>
<td>Stroke distance (m)</td>
<td>1.97 ± 0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke index</td>
<td>2.7 ± 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[La^-] (mmol)</td>
<td>11.9 ± 1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrostatic lift</td>
<td>2.13 ± 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO2max (ml·kg⁻¹·min⁻¹)</td>
<td>70.5 ± 6.5</td>
<td>71.8 ± 7.6</td>
<td>-0.84 b</td>
</tr>
<tr>
<td>Peak power output (W)</td>
<td>388.7 ± 38.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power:Weight (W·kg⁻¹)</td>
<td>5.4 ± 0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak treadmill speed (km·h⁻¹)</td>
<td>22.0 ± 0.7</td>
<td>-0.89 b</td>
<td></td>
</tr>
<tr>
<td>TVent (ml·kg⁻¹·min⁻¹)</td>
<td>45.5 ± 7.5</td>
<td>51.7 ± 7.7</td>
<td></td>
</tr>
<tr>
<td>TVent (%VO2max)</td>
<td>64.5 ± 8.7</td>
<td>72.0 ± 6.6</td>
<td></td>
</tr>
<tr>
<td>Power at TVent (W)</td>
<td>230.0 ± 25.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power:Weight TVent (W·kg⁻¹)</td>
<td>3.3 ± 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed TVent (km·h⁻¹)</td>
<td>17.3 ± 1.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCT (ml·kg⁻¹·min⁻¹)</td>
<td>56.2 ± 5.7</td>
<td>62.4 ± 9.7</td>
<td></td>
</tr>
<tr>
<td>RCT (%VO2max)</td>
<td>79.6 ± 1.8</td>
<td>86.7 ± 6.0</td>
<td></td>
</tr>
<tr>
<td>Power at RCT (W)</td>
<td>316.0 ± 27.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power:Weight at RCT (W·kg⁻¹)</td>
<td>4.5 ± 0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed at RCT (km·h⁻¹)</td>
<td>20.1 ± 1.6</td>
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Note: [La^-] = lactate concentration; TVent = ventilatory threshold; RCT = respiratory compensation threshold.
Significantly correlated:  a with 1500-m swim;  b with 10-km run.

olds, peak running velocity, PPO, velocity and power at TVent, and RCT or the power:weight ratio (P:W), were correlated with overall performance. The only parameters correlated with overall triathlon time were lactate concentration noted at the end of the cycle segment ($r = 0.83, p < 0.05$) and the distance covered during the running part of the submaximal C-R test ($r = -0.92, p < 0.01$). The time in the 400-m swim and triathlete height were correlated with the 1500-m triathlon swim ($r = 0.84, p < 0.04$, and $r = -0.89, p < 0.02$, respectively); however, neither SI nor SL were correlated with swim performance. The running performance of the triathlon was correlated with both ST ($r = 0.93, p < 0.007$), running VO2max ($r = -0.84, p < 0.04$), and velocity at VO2max ($r = -0.89, p < 0.007$).

The best predictors of overall triathlon time, as determined by stepwise multiple linear regression analyses, were distance covered during the run in C-R and the lactate concentration noted at the end of cycling in C-R ($r = 0.96, p < 0.02$). The high $R^2$ value of 0.93 indicated that, taken together, these two laboratory measures could account for 93% of the variance in race times during a drafted triathlon.
Predicted Triathlon Time (s) = –1.128 (distance covered during R of C-R [m])
+ 38.8 ([lactate] at the end of C in C-R) + 13,338.

Figure 1 illustrates the relationship between actual triathlon time and predicted triathlon time. The predicted race time for the elite triathletes was almost 3 s lower than their actual performance (6483 ± 207 vs. 6480 ± 209 s, for the predicted and actual race time, respectively).

Moreover, when one considers only the actual race time, i.e., triathlon time (RT) minus the “change time,” or the time spent changing from swimming to cycling and from cycling to running, which was a mean of 194 ± 27 s, these two measures are highly correlated with RT (r = 0.97, p < 0.011) with an R² of 0.95. This indicates that these two laboratory measures together may account for 95% of the variance in racing times during a drafted triathlon.

Predicted Racing Time (s) = –1.018 (distance covered during R of C-R [m])
+ 39.1 ([lactate] at the end of C in C-R) + 12,518.

Discussion

The physical characteristics (height, weight) of the elite triathletes in the current study were similar to those reported for triathletes of a wide range of abilities (O’Toole and Douglas, 1995). They were also similar to those reported by Schabort et al. (2000) for internationally-ranked triathletes. It is also interesting to note that their average age was lower than the ages usually reported (O’Toole and Douglas, 1995) but similar to those of triathletes in recent studies (Basset and Boulay, 2000). This likely reflects the fact that the athletes of our study had chosen the triathlon as their first sport, not after years of competition in a single sport (Hue et al., 2000a).
Although the VO2 max values in cycling and running were similar to those usually reported for elite triathletes (Schabort et al., 2000; Sleivert and Rowland, 1996), the 3–6% difference usually reported between cycling and running VO2 max was not noted (Basset and Boulay, 2000; Schabort et al., 2000). This may be explained by general cross-training adaptations (Hue et al., 2000a).

Ventilatory threshold and RCT were similar to those reported in studies using the same method of threshold determination in triathletes (Hue et al., 2000a). The significantly higher RCT in running compared to cycling in our elite triathletes is certainly the expression of higher intensity training in running vs. cycling in order to prepare for international triathlons, all of which permit drafting. Although the PPO of the maximal cycle ergometer test was similar to that recently noted by Schabort et al. (2000), peak treadmill speed was higher than that reported by Schabort et al., probably because of the 0% slope used up to 18 km·h–1 during the incremental running test. Although a mean peak treadmill speed of 22.0 km·h–1 could be considered very high, our triathletes had a maximal aerobic velocity of 20.9 km·h–1 during an indirect continuous running multistage test in outdoor conditions.

Performance in the 400-m swim test, although significantly correlated with the 1500-m triathlon swim segment ($r = 0.83$, $p < 0.038$), was not correlated with overall race time, which agrees with the findings of Schabort et al. (2000). This may have two explanations, the first being that relatively little time in a triathlon is spent swimming. The second possibility is that because the swim segment of the triathlon permits drafting, the strategy is not to swim as fast as possible but to swim fast enough to integrate into the leading pack until the cycling event. This would also explain the lack of correlation between lactate concentration at the end of the swim test and swim performance during the triathlon.

Although Costill et al. (1985) demonstrated significant correlations between swim performance and SI and SL, there was no relationship between SI and SL.

![Figure 1.](image-url)
noted in the 400-m swim test and the 1500-m triathlon swim. As suggested by Schabort et al. (2000), this could be due to the difference between performing the 400-m in a pool and the 1500-m in the sea. However, in the present study it may also be due to the use of wet suits during the 1500-m; SI and SL have been shown to differ between wet-suit and no-wet-suit conditions (Chatard et al., 1985). Also, clusters of swimmers form during the swimming segment of the International Triathlon, and drafting has been shown to influence stroking technique (Chollet et al., 2000). Although the significant correlation between triathlete height and 1500-m performance is unclear, it could be related to the findings of Chatard et al. (1995) and Chollet et al. (2000), who found that leaner swimmers make greater performance gains than their less lean counterparts in drafting conditions during swimming.

The physiological variables measured during the maximal cycling exercise (\(\dot{V}O_2\)\text{max}, PPO, P:W, power output at thresholds) failed to correlate with the cycling time of the triathlon. This was even more surprising because most of these parameters have been shown to be highly correlated with cycling performance. Lindsay et al. (1996) found significant correlation between a 40-km cycling exercise and PPO, and Hawley and Noakes (1992) reported a correlation of −0.91 between a 20-km cycling exercise and PPO in highly trained cyclists. However, during an actual triathlon the results are conflicting. Sleivert and Wenger (1993) failed to find physiological variables correlated with cycling time. Others, however, have reported significant correlations between peak \(\dot{V}O_2\) and performance during the cycling event of an Olympic triathlon distance (Butts et al., 1991; Schabort et al., 2000).

This difference in findings is understandable when the strategy of the international triathlon, which permits drafting, is taken into account. Once clusters are formed at the beginning of the cycling segment, triathletes ride at a relatively easy pace in order to conserve energy for running as fast as possible. In such conditions the race pace seems too low to have any correspondence with peak \(\dot{V}O_2\), PPO, or threshold values. A similar intensity pattern has been described in elite and sub-elite cyclists (Padilla et al., 2000; Palmer et al., 1994), in which the intensity noted during time trials (racers cycling alone) was greater than that of the road race (racers cycling in clusters). This was also demonstrated in triathletes by Hausswirth et al. (1999), who showed significantly lower \(\dot{V}E\), \(\dot{V}O_2\), HR, and [La−] during drafting vs. no-drafting in cycling.

In contrast, the physiological parameters noted during the maximal running test correlated significantly with the running time of the triathlon race. Both peak running \(\dot{V}O_2\) and velocity at peak \(\dot{V}O_2\) were highly correlated with running performance during the triathlon (\(r = -0.84, p < 0.007\), \(r = -0.89, p < 0.005\), for \(\dot{V}O_2\) peak and peak velocity at \(\dot{V}O_2\), respectively). This has also been demonstrated by others (Butts et al., 1991; Schabort et al., 2000) and is in accordance with the need for fast running during the triathlon in order to avoid clusters.

Although earlier studies demonstrated a significant relationship between performance and running economy in triathletes (Laurenson et al., 1993), we found no correlation between triathlon running time and running economy during the submaximal tests (R of C-R and R). Furthermore, we found no correlation between triathlon running time and the difference in running economy between C of C-R and R. This is even more surprising because Millet et al. (2000) recently demonstrated that discrimination between triathlete performances may be related
to the difference in energy cost of running in running after cycling vs. running alone. Elite triathletes decrease their energy cost of running after cycling, whereas midlevel triathletes increase it. Similarly, the increase in $V_{E}$ in the run of C-R compared with R was not correlated with running performance during the triathlon. Yet it was recently suggested as being an important factor in performance (Hue et al., 1999) and has been shown to be significantly higher in midlevel vs. elite triathletes (Hue et al., 2000b). The distance covered during running in the submaximal cycle-run test, however, was highly correlated with running performance ($r = -0.94, p < 0.005$), which demonstrates the reliability of the submaximal cycle-run test to estimate the run time of the drafted triathlon.

Physiological variables such as $V_{O2\max}$, the ventilatory and respiratory compensation thresholds, PPO, peak treadmill speed, P:W, and velocity and power output at thresholds were not correlated with overall triathlon time. Although most studies have reported correlation between running speed at the ventilatory threshold and overall performance (Sleivert and Wenger, 1993), or between $V_{O2\max}$ and overall performance (Butts et al., 1991; Miura et al., 1997), we failed to find such relationships.

The predictors of triathlon performance were lactate concentration noted at the end of the cycle segment ($r = 0.83, p < 0.05$) and the distance covered during the run in the C-R test ($r = -0.92, p < 0.01$). These results certainly indicate that triathletes need to place great emphasis (a) on conserving as much energy as possible while cycling in the drafting position, and (b) on running as fast as possible after cycling in triathlons that permit drafting. Multiple linear regression improved the prediction of triathlon performance over that provided by simple correlations. The association of lactate concentration at the end of the cycle segment of C-R and the distance covered during the subsequent run had a correlation coefficient of 0.96 ($p < 0.02$) with an $R^2$ of 0.93. This indicates that, taken collectively, these two laboratory measures could account for 93% of the variance in race times during a drafted triathlon.

During an Olympic-distance triathlon without drafting, athletes cycle as fast as possible and cycling time has been shown to be the most important factor in overall time ($r = 0.98$; Schabort et al., 2000). In the present study the correlation was lower ($r = 0.87, p < 0.05$) because drafting enables riders to conserve energy during the cycling segment and improve the run segment, as demonstrated by Hausswirth et al. (1999). The lactate concentration noted at the end of cycling in the present study was similar to that reported by Hausswirth et al. (1999) during cycling with drafting, which indicates the validity of the laboratory cycling test to assess performance in outdoor drafting conditions. Indeed, the triathletes rode as fast as possible, but the lack of wind resistance put them in energy conditions similar to outdoor drafting (55 ml·kg$^{-1}$·min$^{-1}$ at 39.6 km$^{-1}$·h$^{-1}$ for Hausswirth in French elite triathletes of similar abilities vs. 50.6 ml·kg$^{-1}$·min$^{-1}$ for 38.9 km$^{-1}$·h$^{-1}$ in the present study).

The data of this study indicate that, in order to conserve energy for running as fast as possible, triathletes need to have high maximal and threshold values during the cycling segment of triathlons that permit drafting. This is emphasised by the finding that low blood lactate concentration at the end of cycling was associated with a greater ability to run fast, and thus with overall triathlon perfor-
mance. In fact, it appears that the C-R test may be reliable for predicting drafted-triathlon performance. Comparison of the different protocols used with triathletes in previous studies (Hue et al., 1999; 2000b; 2000c) suggests that laboratory tests in which subjects choose their own workload may be more reliable than tests that require them to exercise to exhaustion at a constant workload. This observation, previously noted in cyclists (Schabort et al., 1998), seems to be even more important in triathletes, for whom performance is dependent on the optimal management of the different race segments (Kuipers et al., 1985).

To summarise, the most important finding of the present study was that two variables measured in a laboratory test were able to predict elite triathlete performance time in a drafted Olympic-distance triathlon. The distance covered in the 20 min of running in a cycle-run test and the blood lactate concentration at the end of the 30 min of cycling in the same test best predicted race time. The correlation coefficient of 0.96, with an $R^2$ of 0.93 determined by multiple stepwise linear regression, indicates that these two laboratory measures together could account for 93% of the variance in race times during a drafted Olympic-distance triathlon.

References


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