Prediction of triathlon race time from laboratory testing in national triathletes

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ABSTRACT

SCHABORT, E. J, S. C. KILLIAN, A. ST CLAIR GIBSON, J. A. HAWLEY, and T. D. NOAKES. Prediction of triathlon race time from laboratory testing in national triathletes. *Med. Sci. Sports Exerc.*, Vol. 32, No. 4, pp. 844–849, 2000. **Purpose:** Four days after competing in an Olympic-distance National Triathlon Championship (1500-m swim, 40-km cycle, 10-km run), five male and five female triathletes underwent comprehensive physiological testing in an attempt to determine which physiological variables accurately predict triathlon race time. **Methods:** All triathletes underwent maximal swimming tests over 25 and 400 m, the determination of peak sustained power output (PPO) and peak oxygen uptake ($\dot{V}O_{2peak}$) during an incremental cycle test to exhaustion, and a maximal treadmill running test to assess peak running velocity and $\dot{V}O_{2peak}$. In addition, submaximal steady-state measures of oxygen uptake ($\dot{V}O_2$), blood [lactate], and heart rate (HR) were determined during the cycling and running tests. **Results:** The five most significant ($P < 0.01$) predictors of triathlon performance were blood lactate measured during steady-state cycling at a workload of 4 W·kg^{-1} body mass (BM) (r = 0.92), blood lactate while running at 15 km·h^{-1} (r = 0.89), PPO (r = 0.86), peak treadmill running velocity (r = 0.85), and $\dot{V}O_{2peak}$ during cycling (r = 0.85). Stepwise multiple regression analysis revealed a highly significant (r = 0.90, $P < 0.001$) relationship between predicted race time (from laboratory measures) and actual race time, from the following calculation: race time (s) = −129 (peak treadmill velocity [km·h^{-1}]) + 122 ([lactate] at 4 W·kg^{-1} BM) + 9456. **Conclusion:** The results of this study show that race time for top triathletes competing over the Olympic distance can be accurately predicted from the results of maximal and submaximal laboratory measures. **Key Words:** CYCLE, LACTATE, RUNNING, OXYGEN UPTAKE, SWIMMING.

Unlike the individual sports that comprise the triathlon (swimming, cycling, and running) in which the correlation between performance and the corresponding physiological variables measured in the laboratory have extensively been studied (1,3,4,8,9,12,17,24), few studies have assessed the relationship between triathletes' race performances and any single or a combination of physiological variables. Furthermore, studies to date either have described the physical characteristics (5,14,18,20,27,28) and response of triathletes to simulated competition (11,27), or have investigated recreational triathletes (27) or triathletes of a wide range of abilities (11). To the best of our knowledge, no study to date has examined the physiological profiles of National class Olympic-distance triathletes or attempted to predict overall performance times of Olympic-distance triathletes by making use of physiological test results.

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Accordingly, the first aim of the current investigation was to assess the physiological status of National class male and female triathletes during the competitive season. A second purpose of the study was to determine whether any of the physiological variables measured during conventional laboratory testing could accurately predict race time in triathlon competition.

METHODS

Subjects and overview of testing procedures. Ten triathletes (5 male and 5 female), who were all members of the South African National team, participated in this study, which was approved by the Research and Ethics committee of the University of Cape Town Medical School. Written informed consent was obtained from each triathlete before their participation in the study. At the time of the investigation, subjects had just competed in the South African National Triathlon Championships, which were held at sea level on a flat out-and-back course and consisted of a 1500-m sea swim, a 40-km cycle, and 10-km run. The weather conditions during the race were 22.7°C, 89 kPa humidity, with a wind speed of 4.2 m·s^{-1}.

Four days after competing in the National Championships, the triathletes reported to the laboratory where they completed 4 d of laboratory performance testing. On day 1, body mass (BM), height, and anthropometrical measurements were recorded for the estimation of percentage body fat (6). On the morning of the second day, a maximal swimming test was performed, while a maximal cycle test was undertaken in the afternoon. On the third day, all submaximal cycling tests were completed, and on the fourth and final day, all running tests were performed. This schedule was designed to maximize the athlete's recovery time between the testing sessions.

Swimming testing. After a self-selected warm-up, each triathlete performed three maximal 25-m freestyle time trials in a heated 25-m indoor swimming pool. The justification for including such a short sprint was that previous research has shown a high correlation ($r = 0.82$) between 22.9-m (25-yd) and 457-m (500-yd) swim time (25). The temperature of the water was maintained at ~26°C for all tests. The 25-m sprints were performed with a 3- to 5-min rest between each swim. After a further 10–15 min of rest, triathletes then performed a maximal 400-m freestyle timed swim. During both the 25-m and 400-m time trials, the number of strokes taken per length were counted to calculate the average stroke distance (D_s). The D_s and swimming velocity (V_s, $m \cdot s^{-1}$) were then used to calculate stroke index (SI) by multiplying V_s by D_s. This index assumes that at a given velocity, the swimmer that moves the greatest distance per stroke has the most effective swimming technique (3).

Cycling testing. Both maximal and submaximal cycle tests were performed on an electronically braked cycle ergometer (Lode, Groningen, The Netherlands). The ergometer was equipped with a racing seat, low-profile handlebars, and pedals for cleated shoes. Triathletes wore their own cycling shoes during all testing.

Before the subsequently described tests for the determination of peak oxygen consumption ($\dot{V}O_{2peak}$) and peak power output (PPO), the cycle ergometer was adjusted to each triathlete's preferred position, after which they were allowed a self-paced warm-up. The incremental test commenced at an intensity equivalent to 3.33 $W \cdot kg^{-1}$ BM for all triathletes. This initial exercise intensity was maintained for 150 s, after which it was increased by 50 W for the male and 25 W for the female triathletes. This workrate was maintained for a further 150 s, after which the exercise intensity increased by 25 W every 150 s for all triathletes until exhaustion (8).

During the maximal cycling tests, subjects wore a mask covering both the nose and mouth. Expired air was passed through an on-line computer system attached to an Oxycon Alpha automated gas analyzer (Mijnhardt, Netherlands) for the determination of $\dot{V}O_{2peak}$, carbon dioxide production, respiratory exchange ratio, and ventilation rate at 10-s intervals. Before each test, the gas analyser was calibrated with a Hans Rudolph 5530 3-L syringe (Kansas City, MO) and a CO_2:N_2 gas mixture of known composition. Each subject's $\dot{V}O_{2peak}$ was taken as the highest oxygen consumption measured during any 60-s period of the incremental test. PPO was defined as the highest workload the subject could complete for 150 s. When the exercise intensity could not be maintained for the full 150 s, PPO was calculated by adding the fraction of the last, uncompleted workload to the preceding, completed workload:

$$PPO(W) = W_{final} + [(t/150) \times 25]$$

where PPO is the peak sustained power output in W, W_{final} is the last exercise intensity the cyclist completed for 150 s in W, and t is the number of seconds for which the final, uncompleted exercise intensity was sustained (8).

The submaximal cycling tests were conducted on a separate occasion. After a standardized 5-min warm-up at an exercise intensity equivalent to 2 $W \cdot kg^{-1}$ BM, triathletes performed two consecutive, steady-state rides of 10 min each at workloads of 3 $W \cdot kg^{-1}$ BM and 4 $W \cdot kg^{-1}$ BM. Throughout the last 5 min of both rides, the triathletes breathed into a face mask through which expired air was passed to an "on-line" gas analyzer (described previously) for determination of oxygen consumption.

Cycling efficiency was calculated from oxygen consumption values averaged over the final 5 min of each workload, and the corresponding power output during that workload, from the following equation (13):

$$\text{Mechanical efficiency} = (60 \times W)/(20934 \times \dot{V}O_2) \times 100$$

where W = workload; $\dot{V}O_2$ = oxygen uptake ($L \cdot min^{-1}$).

Before commencing the submaximal cycling and subsequently described running tests, a 20-gauge Jelco cannula (Critikon, Halfway House, RSA) was inserted into the subject's antecubital vein. During the final 30 s of each workload, blood samples (5 mL) were obtained for the subsequent determination of plasma lactate concentrations. The blood samples were placed into tubes containing potassium oxalate and sodium fluoride and kept on ice until centrifuged at 3000 $rev \cdot min^{-1}$ for 10 min at 4°C. The supernatant was stored at −20°C for later analysis. Plasma lactate concentrations were determined in duplicate by spectrophotometric (Beckman Spectrophotometer, M35) enzymatic analysis (Lactate PAP, bioMerieux Kit, Marcey L'Etoile, France). The coefficient of variation for this assay in our laboratory is <3% for duplicate lactate samples.

Running tests. Tests to determine submaximal running economy were all performed on a motor-drive treadmill (Quinton, Tierney Electrical Motor Co., Seattle, WA) set a gradient of 1°. After a standardized warm-up during which the female triathletes ran at 10 $km \cdot h^{-1}$ and the male triathletes at 12 $km \cdot h^{-1}$ for 5 min, the triathletes completed three 6-min submaximal runs. The speed of the three stages was 11, 13, and 15 $km \cdot h^{-1}$ for female triathletes, whereas the male triathletes ran at 13, 15, and 17 $km \cdot h^{-1}$. Immediately after each stage, the treadmill was stopped for 60 s, during which time a blood sample was taken for later analysis of plasma lactate concentrations.

Subjects rested for 5 min after the final submaximal run before commencing the incremental running test to exhaustion. This maximal test began at a speed of 11 $km \cdot h^{-1}$ for

TABLE 1. Descriptive characteristics of male and female triathletes.

	Age (yr)	Weight (kg)	Height (cm)	Body Fat (%)
Male (n = 5)				
Mean	23	72.1	181	9.7
SD	4	4.7	1.64	2.4
Range	17–27	65.7–76.0	180–184	6.6–12.6
Female (N = 5)				
Mean	25	59.3	167	19.5
SD	7	5.8	4.2	2.4
Range	18–34	51.7–65.5	164–174	16.3–22.6

Values are mean ± SD.

the female and 13 km·h^{-1} for the male triathletes. The initial speed was maintained for 60 s, after which it was increased by 1 km·h^{-1} every minute until volitional fatigue. The triathlete's peak treadmill velocity was taken as the highest speed they maintained for 60 s. When they were unable to complete a full 60 s at the required speed, peak treadmill running speed was determined as a fraction of the final speed added to the velocity of the immediately preceding completed speed. Throughout both the submaximal running economy and maximal treadmill tests, expired air was collected as described previously. The runner's $\dot{V}O_{2peak}$ was taken as the highest oxygen consumption measured during any 60 s of the test. Throughout both the submaximal and maximal tests, the triathletes wore a mask covering the nose and mouth; the expired air passed through an "on-line" computer system as described previously.

Statistical analysis. All values are presented as mean ± standard deviation (SD). Pearson's product moment correlations describe the relationships between the individual physiological variables measured and race performance in each phase of the triathlon as well as overall race performance time for all triathletes. A stepwise multiple linear regression analysis was used to determine the best predictors of overall race time. For all statistics, a significance level of $P < 0.05$ was preset. A correlation coefficient of r > 0.73 was calculated as being significant.

RESULTS

The descriptive characteristics of the triathletes under investigation are shown in Table 1. Table 2 displays the overall race times along with the splits for each segment of the race. The corresponding correlation coefficients for each segment of the race versus the overall race time are also shown (Table 2). For both male and female triathletes, the time for the cycle section was significantly related to total race time (r = 0.98, and r = 0.84, $P < 0.01$ for male and female triathletes, respectively). In addition, the running time was also significantly correlated to overall competition time (r = 0.93, $P < 0.01$) for male, but not female, triathletes.

The peak physiological values attained during cycle ergometry and treadmill running, along with the time and stroke characteristics obtained during the 400-m maximal swim, for male and female triathletes are shown in Table 3. The combined data ($N = 10$) revealed that the $\dot{V}O_{2peak}$ values attained during the treadmill run were significantly higher than during the cycle test (68.8 ± 7.4 mL·kg^{-1}·min^{-1} vs 65.6 ± 6.3 mL·kg^{-1}·min^{-1}, $P < 0.05$).

Selected submaximal physiological responses to cycling and running are reported in Table 4. These variables, for male and female triathletes combined, include submaximal cycling at a workload of 4 W·kg $^{-1}$ BM and running at 13 km·h^{-1} and 15 km·h^{-1}. To relate these results to split- and overall race performance, correlation coefficients were calculated for both maximal (Table 5) and submaximal (Table 6) physiological test variables. Performance in the swim section (1500 m) of the triathlon was best correlated to 400-m time-trial time (r = 0.73). All running and cycling maximal variables, except for power:weight ratio and $\dot{V}O_{2peak}$ (L·min^{-1}), were significantly ($P < 0.01$) related to both split- and overall race time (Table 5).

No swimming variable was significantly related to either split- or overall race time. In cycling, the %$\dot{V}O_{2peak}$ at both 3 W·kg^{-1} and 4 W·kg^{-1} BM was significantly ($P < 0.01$) correlated to split race time, whereas only %$\dot{V}O_{2peak}$ at 4 W·kg^{-1} BM was significantly correlated to overall race time (Table 6). The blood lactate concentration at 4 W·kg^{-1} significantly correlated ($P < 0.01$) to both split- and overall race time. At both running speeds of 13 km·h^{-1} and 15 km·h^{-1}, the fractional utilization (% of $\dot{V}O_{2peak}$) correlated significantly ($P < 0.01$) to split- and overall race time, whereas blood lactate concentration for both running velocities was only correlated to overall race time ($P < 0.001$).

The best predictors of overall race time, as determined by stepwise multiple linear regression analyses, were peak treadmill running velocity and the lactate concentration at 4 W·kg^{-1} BM during submaximal cycling. The following

TABLE 2. Swim (1500 m), cycle (40 km), run (10 km), and overall triathlon performance times for male (N = 5) and female (N = 5) triathletes.

	Swim (min:s)	Cycle (min:s)	Run (min:s)	Overall (min:s)
Male (N = 5)				
Mean	21:36	62:19	36:31	120:26
SD	1:05	2:14	2:53	4:50
Range	20:18–22:45	60:44–66:14	34:21–41:28	116:45–128:42
Correlation with overall time	−0.08	0.98*	0.93*	
Women (N = 5)				
Mean	22:14	70:07	43:05	135:27
SD	2:26	2:00	2:20	5:14
Range	20:08–26:26	66:47–72:06	40:25–46:43	129:14–141:07
Correlation with overall time	0.75*	0.84*	0.74*	

Values are mean ± SD.
* Significantly correlated to overall race time (r > 0.73).

TABLE 3. Maximal physiological variables for swimming, cycle ergometry, and treadmill running in male and female triathletes.

	Males (N = 5)	Females (N = 5)	Group (N = 10)
Swimming			
400-m time (s)	279.8 ± 19.9	326.4 ± 28.0	303.1 ± 33.6
D_s (m)	1.18 ± 0.10	1.02 ± 0.04	1.10 ± 0.12
SI	1.7 ± 0.3	1.3 ± 0.1	1.5 ± 0.3
Cycling			
PPO (W)	385 ± 14	282 ± 19	333 ± 57
P:W ($W \cdot kg^{-1}$)	5.4 ± 0.4	4.9 ± 0.5	5.12 ± 0.5
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	69.9 ± 4.5	61.3 ± 4.6	65.6 ± 6.3
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	5.0 ± 0.4	3.6 ± 0.4	4.3 ± 0.8
Running			
Peak treadmill speed ($km \cdot h^{-1}$)	20.9 ± 0.9	18.0 ± 0.9	19.5 ± 1.8
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	74.7 ± 5.3*	63.2 ± 3.6	68.9 ± 7.4*
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	5.3 ± 0.5	3.7 ± 0.3	4.5 ± 1.0

D_s, stroke distance; SI, stroke index; PPO, peak power output; P:W, power:weight ratio; $\dot{V}O_{2peak}$, peak oxygen uptake.
Values are mean ± SD.
* Significantly higher than cycling $\dot{V}O_{2peak}$ values ($P > 0.05$).

equation was derived to predict overall race time for male and female triathletes. Such an approach is justified because the individual relationships between predicted race time and laboratory variables was colinear for both groups.

$$\text{Predicted Race Time (s)} = -129(\text{Peak tread mill speed } [km \cdot h^{-1}]) + 122([\text{lactate}]\text{at4 } W \cdot kg^{-1} \text{ BM}) + 9456$$

Figure 1 illustrates the relationship between actual race time and predicted race time. The predicted race time for male triathletes based on the above equation was 7.7 s faster, whereas the predicted times for female triathletes were on average 6.6 s slower than their actual performance. For male and female triathletes combined ($N = 10$), the difference between actual and predicted race time was 0.54 s faster. As such, there was a highly significant correlation between predicted and actual race time ($r = 0.90$, $P < 0.01$).

DISCUSSION

The physical characteristics of both male and female triathletes in the current study were similar to those previously reported in the literature (10,18,19,22,27). Mean $\dot{V}O_{2max}$ values for triathletes during treadmill running are reported to range from 52 to 72 $mL \cdot kg^{-1} \cdot min^{-1}$ in men and 59–66 $mL \cdot kg^{-1} \cdot min^{-1}$ in women (20), with cycling $\dot{V}O_{2max}$ values expected to be 5–8% (2), or as much as 9–10% lower (18) compared with running values. The difference between cycling and running $\dot{V}O_{2max}$ values in the present study was ~5%. However, it should be noted that our test was performed on a treadmill with a gradient of only 1%. Other protocols using increasing gradient to exhaustion may elicit higher values for $\dot{V}O_{2peak}$. The wide range in $\dot{V}O_{2max}$ values reported by various investigators (14,20,28) suggest that factors other than $\dot{V}O_{2max}$ contributes more significantly to triathlon performance (18,20). The higher $\dot{V}O_{2max}$ values obtained by athletes in single-sport events also suggests a need for specificity of training in the discipline in which the triathlete performs the poorest (28).

Whereas many studies have reported the physiological characteristics of elite single-sport athletes and the physical factors associated with success in a particular event, few have focused on triathletes and the physiological requirements to achieve peak performance.

The blood lactate concentration measured during submaximal cycling at 4 $W \cdot kg^{-1}$ BM was one of the two test variables that significantly predicted race performance time and correlated to both the 40-km cycle leg and overall triathlon performance time ($r = 0.90$ and $r = 0.92$, respectively). To the best of our knowledge, no previous studies have reported a relationship between blood lactate concentration measured during steady-state cycling at an intensity close to race pace and cycling performance in triathletes. However, such a finding is perhaps not entirely surprising, because this workload corresponds to the maximal steady-state intensity trained cyclists can sustain during a 40-km time-trial (15). Of interest are the data of Coyle et al. (4). These workers reported that the $\dot{V}O_2$ at lactate threshold was a strong predictor of 40-km time-trial performance in highly trained cyclists. They also found that 40-km time-trial performance was highly correlated ($r = -0.88$) to the average workrate their cyclists could sustain for 1 h. In the current study, the absolute values for both $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$) and PPO (W) were better predictors of 40-km time-trial

TABLE 4. Submaximal physiological variables for swimming, cycle ergometry, and treadmill running in male and female triathletes.

	Males (N = 5)	Females (N = 5)	Group (N = 10)
Cycling (Workload: 4 $W \cdot kg^{-1}$)			
Average power output (W)	287 ± 18	234 ± 25	260 ± 35
% PPO	74.5 ± 4.0	83.0 ± 8.6	78.8 ± 7.9
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	57.0 ± 3.4	56.2 ± 2.7	56.6 ± 2.9
$\dot{V}O_2$ ($L \cdot min^{-1}$)	4.1 ± 0.4	3.4 ± 0.2	3.8 ± 0.5
$\%\dot{V}O_{2peak}$	81.8 ± 7.9	91.2 ± 3.5	86.0 ± 7.8
Efficiency (%)	20.3 ± 1.3	20.6 ± 1.0	20.4 ± 1.1
Lactate ($mmol \cdot L^{-1}$)	3.8 ± 1.1	8.2 ± 2.2	6.0 ± 2.8
Running			
13 $km \cdot h^{-1}$			
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	51.0 ± 4.6	51.9 ± 2.7	51.5 ± 3.6
$\dot{V}O_2$ ($L \cdot min^{-1}$)	3.6 ± 0.2	3.0 ± 0.3	3.3 ± 0.4
$\%\dot{V}O_{2peak}$	68.2 ± 4.0	82.5 ± 7.0	75.4 ± 9.2
Lactate ($mmol \cdot L^{-1}$)	1.2 ± 0.2	2.4 ± 1.1	1.9 ± 1.0
15 $km \cdot h^{-1}$			
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	58.4 ± 5.5	60.1 ± 2.0	59.2 ± 4.0
$\dot{V}O_2$ ($L \cdot min^{-1}$)	4.2 ± 0.3	3.5 ± 0.3	3.8 ± 0.4
$\%\dot{V}O_{2peak}$	78.2 ± 5.0	95.2 ± 2.3	86.7 ± 9.7
Lactate ($mmol \cdot L^{-1}$)	1.7 ± 0.3	7.2 ± 1.9	4.5 ± 3.1

D_s, stroke distance; SI, stroke index; PPO, peak power output; P:W, power:weight ratio; $\dot{V}O_{2peak}$, peak oxygen uptake.
Values are mean ± SD.

TABLE 5. Correlations of split and overall race times with maximal physiological data (N = 10).

	1500-m Swim	40-km Cycle	10-km Run	Total Time
Swim				
400-m Swimming Time	0.73			0.71
Cycling				
PPO (W)		−0.91*		−0.86*
P:W ($W \cdot kg^{-1}$)		−0.66		−0.63
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)		−0.80*		−0.80*
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)		−0.85*		−0.82*
Running				
Peak treadmill speed ($km \cdot h^{-1}$)			−0.84*	−0.85*
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)			−0.79*	−0.80*
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)			−0.73	−0.80*
% Body Fat	0.05	0.91*	0.84*	0.85*

PPO, peak power output; P:W, power:weight ratio; $\dot{V}O_{2peak}$, peak oxygen uptake.
* Significant correlation ($r > 0.73$; $P < 0.01$).

TABLE 6. Correlations of split and overall race times with submaximal physiological data (N = 10).

	1500-m Swim	40-km Cycle	10-km Run	Total Time
400-m Swim				
V_s	−0.70			−0.67
D_s	−0.34			−0.46
SI	−0.50			−0.55
Cycling				
Workload 1: 3 $W \cdot kg^{-1}$				
% PPO		0.67		0.65
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)		0.06		−0.05
$\dot{V}O_2$ ($L \cdot min^{-1}$)		−0.59		−0.53
% $\dot{V}O_{2peak}$		0.78*		0.73
Efficiency (%)		0.03		0.14
Lactate ($mmol \cdot L^{-1}$)		0.72		0.75*
Workload 2: 4 $W \cdot kg^{-1}$				
% PPO		0.67		0.65
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)		−0.12		−0.15
$\dot{V}O_2$ ($L \cdot min^{-1}$)		−0.57		−0.49
% $\dot{V}O_{2peak}$		0.74*		0.75*
Efficiency (%)		0.12		0.17
Lactate ($mmol \cdot L^{-1}$)		0.90*		0.92*
Running				
13 $km \cdot h^{-1}$				
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)			0.11	0.08
$\dot{V}O_2$ ($L \cdot min^{-1}$)			−0.49	−0.65
% $\dot{V}O_{2peak}$			0.77*	0.76*
Lactate ($mmol \cdot L^{-1}$)			0.69	0.81*
15 $km \cdot h^{-1}$				
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)			0.11	0.06
$\dot{V}O_2$ ($L \cdot min^{-1}$)			−0.47	−0.66
% $\dot{V}O_{2peak}$			0.83*	0.81*
Lactate ($mmol \cdot L^{-1}$)			0.78*	0.89*

V_s, swimming velocity; D_s, stroke distance; SI, stroke index; PPO, peak power output; $\dot{V}O_2$, mean oxygen uptake; $\dot{V}O_{2peak}$, peak oxygen uptake.
* Significant correlation ($r > 0.73$; $P < 0.01$).

performance than either $\dot{V}O_2$ corrected for body mass and power relative to body weight (Table 5).

The second physiological variable that was predictive of overall race time was the peak treadmill running speed. This finding is supported by others (17,24), who have reported significant correlations ranging from 0.89–0.94 between peak treadmill running velocity and running performance of elite runners participating in distances ranging from 5 to 90 km.

Previous studies describing athletes from single sport events have reported that an individual's $\dot{V}O_{2max}$ is a useful predictor of performance in endurance events, especially where subjects are heterogeneous in terms of $\dot{V}O_{2max}$ and performance (22,23). In triathletes, however, some investigators have found $\dot{V}O_{2max}$ to be significantly related to both running and cycling performance (11,22,28), whereas others (18,19,27) have failed to determine any relationships between triathlon performance and either $\dot{V}O_{2max}$ or any measure of ventilatory threshold. The data in the current study revealed high correlations between $\dot{V}O_{2peak}$ values obtained during cycling and running, and both split and overall triathlon race time (Table 5). However, this could be due to both male and female triathletes being included in the sample population. Combining both groups would increase the range of $\dot{V}O_{2peak}$ and performance times and therefore the variability within the group.

Another maximal test parameter that was highly correlated to both 40-km cycle time and overall race time was the PPO attained during the maximal incremental cycling test ($r = -0.91$ and -0.86, respectively). Similarly, Lindsay et al. (15) found a correlation of 0.84 between 40-km cycling performance and PPO for well-trained cyclists, and Hawley and Noakes (8) reported a correlation of −0.91 between PPO and 20-km cycling performance in highly trained cyclists.

It has been suggested that efficiency or economy of motion during the various stages of a triathlon may be more important predictors of performance than an athlete's $\dot{V}O_{2max}$ (11,14,21). In the current study, running economy was determined by measuring the average oxygen consumption at 13 $km \cdot h^{-1}$ and 15 $km \cdot h^{-1}$ and correlating these results to 10-km running and overall race performance. In contrast to others (7,16) who have previously reported significant relationships between 10-km race time and oxygen consumption ($mL \cdot kg^{-1} \cdot min^{-1}$) at 16.1 $km \cdot h^{-1}$ in elite runners, we found no relationship between submaximal running economy and performance.

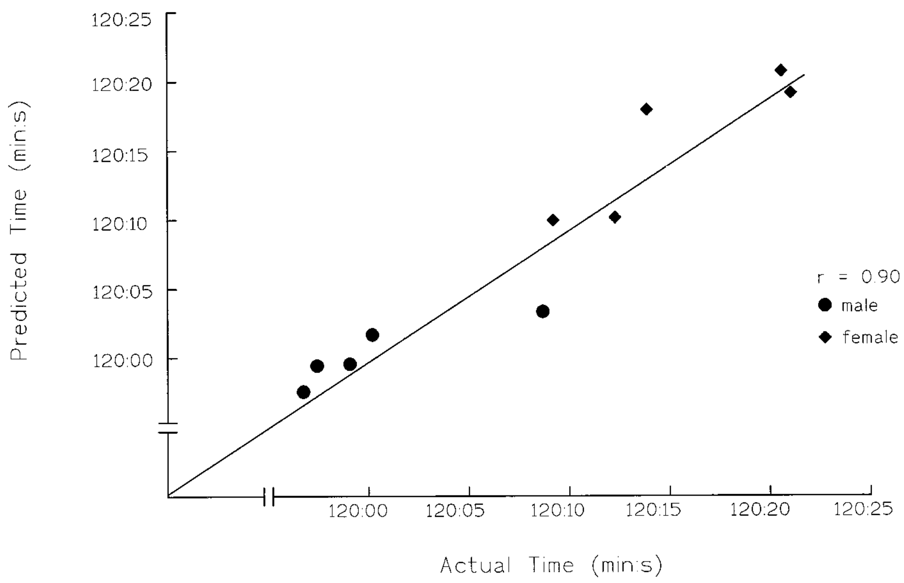

Figure 1—Relationship between actual and predicted race time.

Efficiency can also be measured by determining the fraction of $\dot{V}O_{2max}$ (% $\dot{V}O_{2max}$) that can be sustained at a standardized running or cycling speed. The more efficient triathletes are those exercising at a lower percentage of $\dot{V}O_{2max}$ at a standard exercise intensity. As previously determined (20,28), the percent of $\dot{V}O_{2max}$ sustained during submaximal running and cycling in the current study were significantly related to split- and overall race time. Similarly, high correlations were found between the %$\dot{V}O_{2max}$ at 15 km·h^{-1} and triathlon running time in elite and club level female triathletes (14), as well as between marathon performance and %$\dot{V}O_{2max}$ during a 15 km·h^{-1} submaximal run in athletes of various abilities (26). In the current study, %$\dot{V}O_{2peak}$ maintained during both submaximal running and cycling, was significantly ($r > 0.73$) correlated to split- and overall race time.

In the swimming discipline, 400-m swimming velocity, D_s and SI failed to correlate to either 1500-m swim time or overall race time. These findings are in contrast to the results reported by Costill et al. (3), who determined that, in elite swimmers, the best predictor of performance during a 365.8-m front crawl swim, was D_s ($r = 0.88$). The poor correlation observed in the current study could be due to the 400-m time trial performed in a swimming pool, compared with the 1500-m race time in the sea. Also, on average, only ~17% of total triathlon time is spent swimming, and therefore it is less likely that swimming variables will show high correlations with overall performance time.

To summarize, the most important finding of the current study was that peak treadmill running velocity and blood lactate concentration measured during steady-state cycling at 4 W·kg^{-1} BM, were the variables that best predicted standard-distance triathlon performance. The correlation coefficient of 0.90 determined by multiple stepwise linear regression indicates that, taken collectively, these two laboratory measures could account for 81% of the variance in race times during a standard triathlon (Fig. 1).

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REFERENCES

1. Barlow, K., A. Weltman, R. Schurrer, and J. Henritze. Prediction of maximal effort bicycle ergometer endurance performance. *Int. J. Sports Med.* 6:190–196, 1985.
2. Burke, E. R. Physiological characteristics of competitive cyclists. *Physician Sportsmed.* 8:79–84, 1980.
3. Costill, D. L., J. Kovaleski, D. Porter, J. Kirwan, R. Fielding, and D. King. Energy expenditure during front crawl swimming: predicting success in middle distance events. *Int. J. Sports Med.* 6:266–270, 1985.
4. Coyle, E. F., M. E. Feltner, S. A. Kautz, et al. Physiological and biomechanical factors associated with elite endurance cycling performance. *Med. Sci. Sports Exerc.* 23:93–107, 1991.
5. Dengel, D. R., M. G. Flynn, D. L. Costill, and J. P. Kirwan. Determinants of success during triathlon competition. *Res. Q.* 60:234–238, 1989.
6. Durnin, J. V. G. A., and J. Wormesley. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged 16 to 72 years. *Br. J. Nutrition* 32:77–97, 1974.
7. Farrel, P. A., J. H. Wilmore, E. F. Coyle, J. E. Billing, and D. L. Costill. Plasma lactate accumulation and distance running performance. *Med. Sci. Sport Exerc.* 11:338–344, 1979.
8. Hawley, J. A., and T. D. Noakes. Peak power output predicts maximal oxygen uptake and performance time in trained cyclists. *Eur. J. Appl. Physiol.* 65:79–83, 1992.
9. Hawley, J. A., M. M. Williams, M. M. Vickovic, and P. J. Handcock. Muscle power predicts freestyle swimming performance. *Br. J. Sports Med.* 26:151–155, 1992.
10. Holly, R. G., R. J. Barnard, M. Rosenthal, E. Applegate, and N. Protokin. Triathlete characterisation and response to prolonged strenuous competition. *Med. Sci. Sports Exerc.* 18:123–127, 1986.
11. Kohrt, W. M., D. W. Morgan, B. Bates, and J. S. Skinner. Physiological responses of triathletes to maximal swimming, cycling and running. *Med. Sci. Sports Exerc.* 19:51–55, 1987.
12. Kohrt, W. M., J. S. O'Connor, and J. S. Skinner. Longitudinal assessment of responses by triathletes to swimming, cycling and running. *Med. Sci. Sports Exerc.* 21:569–575, 1989.
13. Kuipers, H. *Variability of Physiological Responses to Exercise.* Haarlem: BV Uitgeverij De Vrieseborch, 1983, p. 26.
14. Laurenson, N. M., K. Y. Fulcher, and P. Korkia. Physiological characteristics of elite and club level female triathletes during running. *Int. J. Sports Med.* 14:455–459, 1993.
15. Lindsay, F. H., J. A. Hawley, K. H. Myburgh, H. H. Schomer, T. D. Noakes, and S. C. Dennis. Improved athletic performance in highly trained cyclists after interval training. *Med. Sci. Sports Exerc.* 28:1427–1434, 1996.
16. Morgan, D. W., and M. Craib. Physiological aspects of running economy. *Med. Sci. Sports Exerc.* 24:456–461, 1992.
17. Noakes, T. D., K. H. Myburgh, and R. Schall. Peak treadmill running velocity during the VO_2peak test predicts running performance. *J. Sports Sci.* 8:35–45, 1990.
18. O'Toole, M. L., W. Douglas, B. Hiller, L. O. Crosby, and P. S. Douglas. The ultraendurance triathlete: a physiological profile. *Med. Sci. Sports Exerc.* 19:45–50, 1987.
19. O'Toole, M. L., P. S. Douglas, and W. D. B. Hiller. Lactate, oxygen uptake, and cycling performance in triathletes. *Int. J. Sports Med.* 10:413–418, 1989.
20. O'Toole, M. L., and P. S. Douglas. Applied physiology of triathlon. *Sports Med.* 19:251–267, 1995.
21. Powers, S. K., S. Dodd, R. Deason, R. Bird, and T. McKnight. Ventilatory threshold, running economy and distance running performance of trained athletes. *Res. Q. Exerc. Sport* 54:179–182, 1983.
22. Roalstad, M. S. Physiological testing of the ultraendurance triathlete. *Med. Sci. Sports Exerc.* 21:S200–S204, 1989.
23. Saltin, B., and P.-O. Astrand. Maximal oxygen uptake in athletes. *J. Appl. Physiol.* 23:353–358, 1967.
24. Scott, B. K., and J. A. Houmard. Peak running velocity is highly related to distance running performance. *Int. J. Sports Med.* 15:504–507, 1994.
25. Sharp, R. L., Troup, J. P., and D. L. Costill. Relationship between power and sprint freestyle swimming. *Med. Sci. Sports Exerc.* 14:53–56, 1982.
26. Sjodin, B., and J. Svedenhag. Applied physiology of marathon running. *Sports Med.* 2:83–99, 1985.
27. Sleivert, G. G., and H. A. Wenger. Physiological predictors of short-course triathlon performance. *Med. Sci. Sports Exerc.* 25:871–876, 1993.
28. Sleivert, G. G., and D. S. Rowlands. Physical and physiological factors associated with success in the triathlon. *Sports Med.* 22:8–18, 1996.