



**HAL**  
open science

# Ventilatory Threshold and Maximal Oxygen Uptake in Present Triathletes

Olivier Hue, Daniel Le Gallais, Didier Chollet, Christian Prefaut

► **To cite this version:**

Olivier Hue, Daniel Le Gallais, Didier Chollet, Christian Prefaut. Ventilatory Threshold and Maximal Oxygen Uptake in Present Triathletes. *Canadian Journal of Applied Physiology*, 2000, 25 (2), pp.102-113. 10.1139/h00-007 . hal-00720566

**HAL Id: hal-00720566**

**<https://hal.univ-antilles.fr/hal-00720566v1>**

Submitted on 24 Jul 2012

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# ***Ventilatory Threshold and Maximal Oxygen Uptake in Present Triathletes***

Olivier Hue, D. Le Gallais, D.Chollet and C.Préfaut

---

## **Catalog Data**

Hue, O., Le Gallais, D., and Préfaut, C. (2000). Ventilatory threshold and maximal oxygen uptake in present triathletes. *Can. J. Appl. Physiol.* 25(2): 102-113. © 2000 Canadian Society for Exercise Physiology.

---

**Key Words:** triathlon, cross-training adaptations, elite triathletes

**Mots-clés:** triathlon, effets-croise, triathletes elites

## **Abstract/Résumé**

*The aim of this study was to determine the physiological profile of young triathletes who began triathlon competition as their first sport. Twenty-nine male competitive triathletes (23 regionally and nationally ranked triathletes and 6 elite, internationally ranked triathletes) performed two tests, one on a cycle ergometer (CE  $\dot{V}O_{2max}$ ) and one on a treadmill (TM  $\dot{V}O_{2max}$ ). Results showed (a) no difference between CE  $\dot{V}O_{2max}$  and TM  $\dot{V}O_{2max}$  in the triathletes ( $69.1 \pm 7.2$  vs.  $70.2 \pm 6.2$  mL · kg<sup>-1</sup> · min<sup>-1</sup>, respectively), (b) values of CE  $\dot{V}O_{2max}$  and TM  $\dot{V}O_{2max}$  in elite triathletes ( $75.9 \pm 5.2$  and  $78.5 \pm 3.6$  mL · kg<sup>-1</sup> · min<sup>-1</sup>, respectively) that were comparable to those reported in elite single-sport athletes in these specialities, and (c) although the ventilatory threshold ( $Th_{vent}$ ) were similar in CE and TM, TM  $Th_{vent}$  was consistently lower for triathletes than TM  $Th_{vent}$  usually reported for runners.*

*Le but de cette étude était de déterminer le profil physiologique de jeunes triathlètes qui ont choisi le triathlon comme premier sport de compétition. En tout, 29 triathlètes masculins ont participé à cette étude (23 de niveau régional ou national et 6 de niveau international,*

---

Olivier Hue, D. Le Gallais, and D.Chollet are with the Laboratoire d'Interface Biopsychosociale des APA, UFR-STAPS, 700 avenue du Pic Saint Loup, 34090 Montpellier, France. C.Préfaut is with the Laboratoire de Physiologie des Interactions, Service Central de Physiologie Clinique, Unité d'Exploration Respiratoire, Centre Hospitalier Universitaire Arnaud de Villeneuve, 34295 Montpellier Cedex 5, France.

Address for correspondence: O. Hue, UFR-STAPS Antilles-Guyane, Campus de Fouillole, BP 592, 97159 Pointe à Pitre Cedex.

*i.e., élite). Ils ont effectué deux tests d'exercice maximal, l'un sur tapis roulant (TM), l'autre sur cycloergomètre (CE). Les résultats sont que (a) il n'existe pas de différence significative entre les valeurs de  $\dot{V}O_{2max}$  relevées sur TM et CE; (b) les valeurs de  $\dot{V}O_{2max}$  relevées chez les triathlètes d'élite sont comparables à celles relevées chez des coureurs ou des cyclistes d'élite; et (c) les seuils ventilatoires sont similaires en CE et en TM, mais le seuil ventilatoire en TM est significativement plus faible chez les triathlètes que chez les coureurs de même niveau.*

## Introduction

Maximal oxygen uptake and anaerobic threshold have been measured for most groups of elite athletes (Bunc et al., 1987; Withers et al., 1981) who train and compete in only one sport, such as running (Powers et al., 1983; Tanaka et al., 1984) or cycling (Coyle et al., 1991; Lucia et al., 1998). In these single sports, values of  $\dot{V}O_{2max}$  have been correlated with training distance and competitive results: the athletes who developed the highest  $\dot{V}O_{2max}$  were those who averaged the highest mileage per week, and, generally, the athletes who had the highest  $\dot{V}O_{2max}$  also had the best results (Hagan et al., 1981; Krebs et al., 1986). Furthermore, the ventilatory threshold ( $Th_{vent}$ ), validated as being concomitant to the anaerobic threshold (Wasserman et al., 1973) has been demonstrated as being a better predictor of distance running and cycling performance than  $\dot{V}O_{2max}$  (Coyle et al., 1991; Powers et al., 1983).

Training induces central adaptations that are important in the development of  $\dot{V}O_{2max}$  (Clausen et al., 1973). However, although in recreational single-sport athletes, testing with a treadmill (TM) usually elicited 6–11% higher  $\dot{V}O_{2max}$  values than with a cycle ergometer (CE) (Astrand, 1970), elite athletes who train only in a single sport have shown a higher  $\dot{V}O_{2max}$  and  $Th_{vent}$  in their speciality (Hagberg et al., 1978), indicating that peripheral adaptations (resulting from training specific to the muscle groups used) are also important in the  $\dot{V}O_{2max}$  development (Clausen et al., 1973).

Numerous studies (Table 1) have reported  $\dot{V}O_{2max}$  and  $Th_{vent}$  values for running and cycling in male triathletes.  $Th_{vent}$  in running, expressed as a percentage of  $\dot{V}O_{2max}$ , has been noted consistently higher in running than in cycling for triathletes (Schneider et al., 1990). The mean  $\dot{V}O_{2max}$  of male triathletes ranged from 57.4 to 75.4 mL · kg<sup>-1</sup> · min<sup>-1</sup> in running and from 54.4 to 70.3 mL · kg<sup>-1</sup> · min<sup>-1</sup> in cycling (O'Toole et al., 1989a, 1995; Schneider et al., 1990) with the difference between TM  $\dot{V}O_{2max}$  and CE  $\dot{V}O_{2max}$  for triathletes (3–6%) less than the difference for single-sports athletes (6–11%). The additive benefits from participation in multisports are commonly referred to as “cross-training” adaptations (Schneider et al., 1990).

Because earlier studies were conducted on triathletes (Delistraty and Noble, 1987; Kohrt et al., 1987; O'Toole et al., 1989) that tended to be older than those of most groups of elite swimmers (Trappe, 1997), cyclists (Wilber et al., 1997), and runners (Robinson et al., 1991) and were initiated to triathlon competition following years of competition in a single sport (Roalstad, 1989), it is unclear if the smaller differences between CM and TR  $\dot{V}O_{2max}$  resulted from physiological adaptations derived from the additive benefits elicited by triathlon training.

The aim of the present study was to examine the metabolic and cardiorespiratory data in triathletes who began the triathlon as their first sport. Our hypothesis

**Table 1 Physical/Physiological Characteristics of Triathletes Reported in Some Previous Studies**

Study	N	Age (yr)	Height (cm)	Weight (kg)	Cycle ergometry $\dot{V}O_2$ (ml · kg <sup>-1</sup> · min <sup>-1</sup> )	Treadmill running $\dot{V}O_2$ (ml · kg <sup>-1</sup> · min <sup>-1</sup> )
Albrecht et al. (1986)	9	28.7	181.6	73.8	56.3	57.7
Hue et al. (1998)	7	20.8	180.4	69.7	65.4	62.1
Kohrt et al. (1987)	8	27.6	179.4	72.8	57.9	60.5
Kreider (1998)	9	27.6	179.4	72.8	64.3	68.1
Miura et al. (1997)	17	26.5	171.1	62.8	61.1	63.8
O'Toole et al. (1989)	8	30.5	178.8	74.7	66.7	68.8
Roalstad (1989)	10	30.5	181.9	76.6	64.3	67.2
Schneider et al. (1990 [elite])	10	27.6	179.3	72.0	70.3	75.4
Sleivert and Wenger (1993)	18	27.7	180.0	76.2	60.1	63.7

was that in such triathletes, because of simultaneous training in cycling and running, (a) TM  $\dot{V}O_{2max}$  and CE  $\dot{V}O_{2max}$  would be equal, and (b) cycling and running  $Th_{vent}$  would occur at a similar %  $\dot{V}O_{2max}$ . Moreover, we further hypothesized that the  $\dot{V}O_{2max}$  values in elite triathletes would be similar to those of elite single-sport athletes, despite lower training distance per week in each sport, which suggest general cross-training adaptations in triathletes.

## Materials And Methods

### SUBJECTS

Twenty-nine male competitive triathletes participated in the present study. Twenty-three were regionally and nationally ranked triathletes, and 6 were elite triathletes who had been chosen to represent France in the International Triathlon Union World Championship. All were students at the School of Physical Education at the University of Montpellier, France, and they were members of the University Athletic

Team, which has been a French national champion in the triathlon for four consecutive years. The subjects had been competing in triathlon for  $6.0 (\pm 2.3)$  years and were in the competitive period at the time they were tested. Anthropometric and training regimen data are reported in Table 2. All subjects were informed of the purpose of the study and gave written consent in accordance with the regional Ethics Committee before participating.

#### TESTING PROTOCOL

The tests were performed by every triathlete who entered the School of Physical Education at the University of Montpellier, France, between 1993 and 1997. Each subject randomly completed two incremental tests that took place over two consecutive weeks. The tests were done at the same time of day and the same day of the week to minimize the influence of the effects of personal training on the study. The subjects were asked to maintain their training schedule for the duration of the study but were not allowed to compete in a triathlon during the testing period. During experiment days, the subjects were asked to abstain from training. The incremental treadmill (Gymroll 1800, Gymroll, Roche La Molière, France) test began at  $5 \text{ km} \cdot \text{h}^{-1}$  for one minute at 0% grade. The speed was then increased by  $1 \text{ km} \cdot \text{h}^{-1}$  every minute up to  $18 \text{ km} \cdot \text{h}^{-1}$ . The slope was then increased by 1% every minute to exhaustion. The incremental cycle (Monark 864, Monark-Crescent AB, Varburg, Sweden) test was performed on an electronically braked cycle ergometer. After 3 min of cycling at 30 W, the power was then increased by 30 W every minute to exhaustion.

#### GAS EXCHANGE MEASUREMENT

The following cardiorespiratory data were measured every minute using a mass spectrometer breath-by-breath automated system (MGA-1100, Marquette, NY, USA): ventilation ( $\dot{V}_E$ ), oxygen uptake ( $\dot{V}O_2$ ), carbon dioxide output ( $\dot{V}CO_2$ ), 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 ( $f_R$ ), and tidal volume ( $\dot{V}_T$ ). Heart rate (HR) was measured

**Table 2** General Physical Characteristics and Training Regimens for the Triathletes (N = 29) and the Subgroup of Elite Triathletes (N = 6)

Swim (N)	Age (yr)	Height (cm)	Weight (kg)	Mean training distances ( $\text{km} \cdot \text{wk}^{-1}$ )		
				Swim	Bike	Run
29	$20.9 \pm 2.6$	$176.9 \pm 8.0$	$68.0 \pm 7.8$	$13.5 \pm 5.5$	$222.0 \pm 100.8$	$38.5 \pm 14.1$
6	$21.8 \pm 2.4$	$178.8 \pm 7.8$	$69.9 \pm 7.3$	$16.3 \pm 2.4$	$345.0 \pm 52.4$	$55.8 \pm 5.8$
<i>P</i> values	NS	NS	NS	NS	0.008	0.007

*Note.* Training distances are average weekly values representing training volumes at the time subjects were tested. NS indicates that the mean value for elite triathletes was not significantly different from the value obtained for all triathletes

using a telemetry system (Polar Racer, Polar Electro, Kempele, Finland). To ensure that  $\dot{V}O_{2\max}$  was attained, at least three of the following four criteria had to be met: (a) an increase in  $\dot{V}O_2$  lower than 100 ml with the last increase in work rate ("leveling off" criterion); (b) attainment of age-predicted maximal HR,  $210 - (0.65 \times \text{age}) \pm 10\%$  (Spiro, 1977); (c)  $R > 1.10$ ; and (d) an inability to maintain the required running speed or the minimal pedaling frequency ( $= 50$  rpm) despite maximal effort and verbal encouragement. The ventilatory threshold ( $Th_{\text{vent}}$ ) was automatically 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 the  $Th_{\text{vent}}$  corresponds to the break point in the  $\dot{V}CO_2$ - $\dot{V}O_2$  relationship. As shown in Figure 1, this method is similar to Wasserman et al. (1973) in which the  $Th_{\text{vent}}$  is indicated by an increase in  $\dot{V}_E/\dot{V}O_2$  without a marked increase in  $\dot{V}_E/\dot{V}CO_2$ .

#### STATISTICAL ANALYSIS

The results are expressed as mean  $\pm$  SD. Maximal exercise data, as well as the metabolic and cardiorespiratory values obtained at the  $Th_{\text{vent}}$  during cycle ergometry and treadmill running, were compared using a Student's paired *t*-test. Statistical significance was defined at  $P < 0.05$ . Simple linear regressions were used to determine the relationship between  $\dot{V}O_{2\max}$  differences between CE and TR ( $CE \dot{V}O_{2\max} - TM \dot{V}O_{2\max}$ ) and differences in training schedule between cycling and running (cycling training schedule - running training schedule,  $h^{-1}$ ) for each triathlete and between cycling and running training schedule and CE and TM  $\dot{V}O_{2\max}$ .

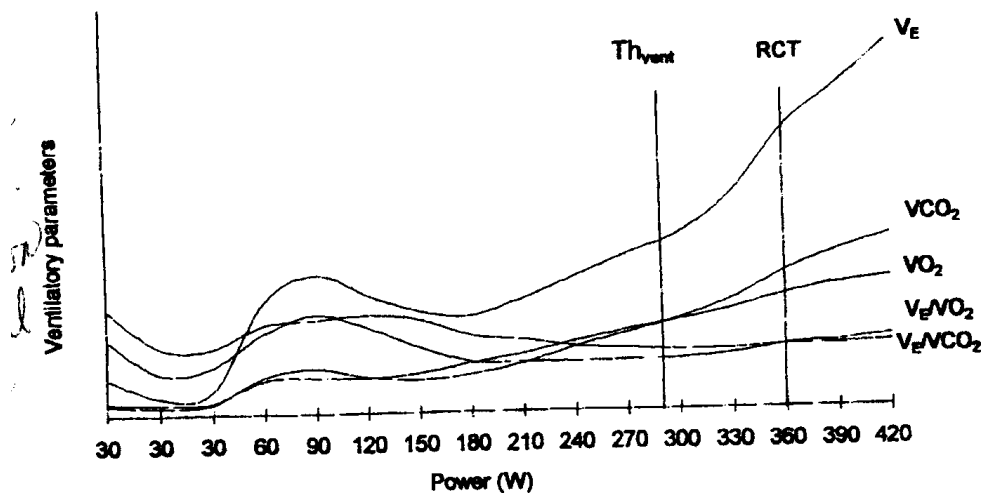


Figure 1. The detection of ventilatory threshold ( $Th_{\text{vent}}$ ) for a representative subject. One can see that both the methods of Beaver et al. (1986) and Wasserman et al. (1973) induce the same  $Th_{\text{vent}}$ . One could also see on this figure the approximate respiratory compensation threshold RCT detection based on the non linear rise in  $\dot{V}_E$  and in  $\dot{V}_E/\dot{V}O_2$ , associated with a rise in  $\dot{V}_E/\dot{V}CO_2$ .

## Results

Maximal metabolic and cardiorespiratory values obtained during cycle ergometry and treadmill running are presented in Table 3. There were no differences between CE  $\dot{V}O_{2\max}$  and TM  $\dot{V}O_{2\max}$ . Maximal HR was significantly lower ( $P < 0.001$ ) for CE than for TM. The maximal  $\dot{V}_T$  reached for CE was significantly higher ( $P < 0.05$ ) than for TM. The maximal  $f_R$  was significantly ( $P < 0.01$ ) lower for CE.

Table 4 presents the mean and standard deviation values for the metabolic and cardiorespiratory variables measured at  $Th_{vent}$  for both modes of exercise. The  $Th_{vent}$  occurred at the same level for both TM and CE. HR at  $Th_{vent}$  was significantly lower ( $P < 0.05$ ) for CE. Tidal volume at  $Th_{vent}$  was significantly higher ( $P < 0.001$ ) and  $f_R$  at  $Th_{vent}$  was significantly lower ( $P < 0.001$ ) for CE than for TM.

We found nonsignificant correlations ( $r = 0.37$ ,  $P = 0.32$ ) between  $\dot{V}O_{2\max}$  differences (CE  $\dot{V}O_{2\max}$  - TM  $\dot{V}O_{2\max}$ ) and training schedule (cycling training schedule - running training schedule,  $h^{-1}$ ) or between training schedule and  $\dot{V}O_{2\max}$  ( $r = 0.56$ ,  $P = 0.13$  and  $r = 0.45$ ,  $P = 0.23$ , for cycling and running, respectively).

**Table 3** Maximum Metabolic and Cardiorespiratory Values Obtained During Incremental Cycle Ergometry and Treadmill Running for All Triathletes (T) and the 6 Elite Triathletes (E)

Variables	Population	Cycle ergometry	Treadmill running	P values
$\dot{V}O_2$ ( $L \cdot \min^{-1}$ )	T	4.70 ± 0.49	4.81 ± 0.42	NS
	E	5.30 ± 0.36	5.49 ± 0.25	NS
$\dot{V}O_2$ ( $mL \cdot kg \cdot \min^{-1}$ )	T	69.1 ± 7.2	70.2 ± 6.2	NS
	E	75.9 ± 5.2	78.5 ± 3.6	NS
HR ( $beats \cdot \min^{-1}$ )	T	180 ± 11	188 ± 7	0.000
	E	174 ± 3	184 ± 5	0.000
R	T	1.16 ± 0.04	1.10 ± 0.04	0.008
	E	1.14 ± 0.04	1.11 ± 0.04	NS
$\dot{V}_E$ ( $L \cdot \min^{-1}$ )	T	143.4 ± 22.3	144.0 ± 18.4	NS
	E	135.5 ± 22.0	140.1 ± 17.8	NS
$\dot{V}_T$ (L)	T	3.00 ± 0.55	2.60 ± 0.41	0.01
	E	3.02 ± 0.59	2.77 ± 0.34	NS
$f_R$ ( $breaths \cdot \min^{-1}$ )	T	48.8 ± 7.6	57.4 ± 11.1	0.01
	E	45.3 ± 4.1	51.1 ± 6.4	0.02

*Note.* P: Comparison between values obtained on cycle ergometer and treadmill running.

**Table 3** Maximum Metabolic and Cardiorespiratory Values Obtained During Incremental Cycle Ergometry and Treadmill Running for All Triathletes (T) and the 6 Elite Triathletes (E)

Variables	Population	Cycle ergometry	Treadmill running	P values
$\dot{V}O_2$ (L · min <sup>-1</sup> )	T	3.01 ± 0.55	3.17 ± 0.55	NS
	E	3.42 ± 0.76	3.55 ± 0.30	NS
$\dot{V}O_2$ (mL · kg · min <sup>-1</sup> )	T	45.1 ± 8.2	46.7 ± 4.1	NS
	E	49.0 ± 10.9	50.9 ± 4.3	NS
% $\dot{V}O_{2max}$	T	65.3	66.4	NS
	E	64.5	64.8	NS
HR (beats · min <sup>-1</sup> )	T	141 ± 16	150 ± 10	0.04
	E	138 ± 13	145 ± 8	NS
$\dot{V}_E$ (L · min <sup>-1</sup> )	T	64.3 ± 10.3	71.5 ± 13.6	NS
	E	63.3 ± 11.2	75.9 ± 12.6	0.03
$\dot{V}_T$ (L)	T	2.43 ± 0.41	1.90 ± 0.27	0.000
	E	2.42 ± 0.30	1.96 ± 0.31	0.001
$f_R$ (breaths · min <sup>-1</sup> )	T	27.7 ± 3.3	41.2 ± 8.7	0.000
	E	26.6 ± 3.8	39.9 ± 5.5	0.000

Note. P: Comparison between values obtained on cycle ergometer and treadmill running.

## Discussion

### PHYSICAL CHARACTERISTICS

The physical characteristics of triathletes have been reported by several investigators (Table 1). Our results are comparable to those reported in previous studies (O'Toole and Douglas, 1995; Roalstad et al., 1989) concerning height, which was reported to be the same as in single-sport athletes (Coyle et al., 1991; Robinson et al., 1991; Trappe et al., 1997), and weight, which tended to be less than the weight of swimmers (Trappe et al., 1997) but greater than that of cyclists (Coyle et al., 1991) and runners (Robinson et al., 1991). The average age of our triathletes was lower than the values usually reported (O'Toole and Douglas, 1995; O'Toole et al., 1989; Roalstad, 1989) but similar to that of most groups of swimmers, cyclists, and runners with the same characteristics of training. This similarity in age could be explained by the fact that our triathletes had chosen the triathlon as their first sport and not following years of competition in a single sport.



## PHYSIOLOGICAL CHARACTERISTICS

**Maximal oxygen uptake.** CE and TM (see Table 3) are in accordance with mean values reported in previous studies: Schneider et al. (1990) reported values that ranged from 54.4 to 66.7 mL · kg<sup>-1</sup> · min<sup>-1</sup> for cycling and 57.4 to 72.0 mL · kg<sup>-1</sup> · min<sup>-1</sup> for running in recreational triathletes. The mean running  $\dot{V}O_{2max}$  of 70.8 mL · kg<sup>-1</sup> · min<sup>-1</sup> compared favourably with the values previously reported for highly trained male distance runners (Powers et al., 1983; Tanaka et al., 1984). Moreover, the mean running  $\dot{V}O_{2max}$  of 78.5 mL · kg<sup>-1</sup> · min<sup>-1</sup> noted in the elite triathletes agrees with the range of 75.4–85.0 mL · kg<sup>-1</sup> · min<sup>-1</sup> reported in high-level triathletes (Schneider et al., 1990; Sleivert and Rowlands, 1996, respectively) and was comparable to the value of 79.3 mL · kg<sup>-1</sup> · min<sup>-1</sup> reported in Olympic runners (Martin et al., 1986). The cycling  $\dot{V}O_{2max}$  of 69.1 mL · kg<sup>-1</sup> · min<sup>-1</sup> for the triathletes was 7–10% higher than the values reported for other competitive male cyclists (Simon et al., 1986; Withers et al., 1981) and comparable to the value of 71.1 mL · kg<sup>-1</sup> · min<sup>-1</sup> reported by Folinsbee et al. (1983) for seven elite cyclists. Moreover, the cycling  $\dot{V}O_{2max}$  of 75.9 mL · kg<sup>-1</sup> · min<sup>-1</sup> noted for the elite triathletes was comparable to the value of 74.0 mL · kg<sup>-1</sup> · min<sup>-1</sup> reported by Burke (1980) for 23 members of the U.S. national cycling team. Since the triathletes of the present study trained less in any one sport than single sport athletes (Table 5) and had not turned to triathlon competition after years of competition in a single sport, the achievement of  $\dot{V}O_{2max}$  values that are comparable to those of elite single-sport athletes may demonstrate an additive effect between sport activities, commonly called “cross-training effect” (O’Toole et al., 1989; Schneider et al., 1990).

For most groups of athletes that train and compete in only one sport, such as running or cycling, the TM test usually elicits higher  $\dot{V}O_{2max}$  than the CE test, with the TM  $\dot{V}O_{2max}$  values reported to be 6–11 % higher (Astrand, 1970). This has also been reported in triathletes but with a smaller difference (3–6%) between TM  $\dot{V}O_{2max}$

**Table 5 Training Regimen Reported in Some Previous Studies for Triathletes Training for Classic Distance Triathlon**

Etude	N	Distance	Swimming (km · wk <sup>-1</sup> )	Cycling (km · wk <sup>-1</sup> )	Running (km · wk <sup>-1</sup> )
Hue et al. (1998)	7	CD	14.7	264.3	44.3
Kreider (1988)	9	CD	6.3	180.0	54.0
Schneider et al. (1990)	10	—	12.4	269.3	54.9
Anderson Jones et al. (1992)*	12	—	59.5	—	—
Coyle et al. (1991)**	15	—	—	539	—
Robinson et al. (1991)***	13	—	—	—	85

*Note.* CD: 1.5 km swim, 40 km cycle, 10 km run or for every distance (—), and for swimmers (\*), cyclists (\*\*), and runners (\*\*\*).

and CE  $\dot{V}O_{2max}$  (Roalstad, 1989; Schneider et al., 1990). This difference is related to the greater muscle mass used in running versus cycling (Pannier et al., 1980; Pechar et al., 1974). We found no difference in  $\dot{V}O_{2max}$  between the two modes of exercise in our study, suggesting general cross-training adaptations due to training in the two sports. These results agree with those of studies comparing the effect of a combined cycle/run training versus a single sport (i.e., running) on  $\dot{V}O_{2max}$  (Foster et al., 1995; Mutton et al., 1993). However, these results that reported short-term cross-training effects (O'Shea, 1991) have been noted in low-level subjects that generally train in single sports.

Our study demonstrates a long-term cross-training effect in elite athletes, which to our knowledge has not been reported before. Indeed, elite athletes who train only in a single sport have a higher  $\dot{V}O_{2max}$  in their speciality (Hagberg et al., 1978; Withers et al., 1981), which indicates that physiological adaptations are specific to the muscle group recruited (Withers et al., 1981). Also, the magnitude of improvement in  $\dot{V}O_{2max}$  in triathletes was reported to depend on the training volume in each of the three components of the sport (Kohrt et al., 1987). Despite these findings, we found nonsignificant correlation between  $\dot{V}O_{2max}$  differences (CE  $\dot{V}O_{2max}$  - TM  $\dot{V}O_{2max}$ ) and training schedule (cycling training schedule - running training schedule,  $h^{-1}$ ) for triathletes or between training schedule for each sport and  $\dot{V}O_{2max}$  for cycling and running, respectively.

**Ventilatory threshold.** Many researchers have studied the anaerobic threshold in male athletes who train in only one sport, such as running or cycling (Bunc et al., 1987; Powers et al., 1983). The values of 66.4% and 64.8% of  $\dot{V}O_{2max}$  reported in the present study, during TM running for the triathletes and the subgroup of elite triathletes, respectively, are lower than the values usually reported for competitive and elite distance runners (70 to 88% of  $\dot{V}O_{2max}$ , respectively; Bunc et al., 1987; Schneider et al., 1990; Withers et al., 1981). This may be attributed to the great difference in running volume during training between distance runners and the triathletes, and more certainly to the fact that competitive and elite distance runners train at a higher intensity and do more interval training in running than do triathletes (Korkia et al., 1994; Schneider et al., 1990). This also may be attributed to the method used for the  $Th_{vent}$  measurement, which could represent, in some cases (Bunc et al., 1987), the detection of the respiratory compensation threshold (RCT) rather than the  $Th_{vent}$ . Our values of 65.3% and 64.5% of  $\dot{V}O_{2max}$  during CE for the triathletes and the elite triathletes, respectively, agree with the value of 66.8% of  $\dot{V}O_{2max}$  reported by Schneider et al. (1990) in triathletes. These values are also comparable to the 66.3% of  $\dot{V}O_{2max}$  detected by Withers et al. (1981) in 10 endurance trained cyclists, while Simon et al. (1986) reported a value of 65.8% of  $\dot{V}O_{2max}$  in 6 highly trained cyclists. The lack of difference in  $Th_{vent}$  for triathletes and cyclists could be attributed to the highly aerobic character of cycling. Indeed, competitive and elite cyclists are reported to do very little interval training but to have a high training volume, and general training volume of triathletes can be favourably compared with that of cyclists (O'Toole, 1989).

The lack of difference between  $Th_{vent}$  in cycling versus running in triathletes agrees with earlier results (Albrecht et al., 1989; Kreider, 1988). In these two studies, values are considerably higher than our values: 78.8% and 79.3% of CE and TM  $\dot{V}O_{2max}$ , respectively, and 85% and 90% of CE and TM  $\dot{V}O_{2max}$ , respectively. These high values should be considered with extreme caution. Indeed, RCT has to

be distinguished from  $Th_{vent}$  (Schneider et al., 1990); RCT usually occurs at a higher percentage of  $\dot{V}O_{2max}$  than  $Th_{vent}$  does. Also, the studies of Albrecht et al. (1989) and Kreider et al. (1988) exist only in an abstract form with no identification of the methods used for detection of  $Th_{vent}$ .

The difference between running and cycling in tidal volume and breathing frequency at  $\dot{V}O_{2max}$  agrees with the findings of Bonsignore et al. (1998). These authors have reported that  $V_T$  and  $f$  were correlated with both the cycle rate and  $CO_2$  production, which indicates that the rhythm of exercise modulated  $f$  and  $V_T$ .

This study demonstrates for the first time that young triathletes, without prior athletic specialization, have the same  $\dot{V}O_{2max}$  for running and cycling. In addition, despite a lower volume of training in each sport, the triathletes and the elite triathletes had cycling and running  $\dot{V}O_{2max}$  values that were comparable to those reported for competitive and elite male cyclists and runners. These findings suggest an important general cross-training adaptation due to simultaneous trainings in the two modes of exercise. However, the lower  $Th_{vent}$  running value of the triathletes in comparison with that of distance runners supports the need of specific training. Indeed, although triathletes benefit from the effect of cross-training, measurable improvement in one specific sport of the triathlon probably requires a training regimen that is specific to that sport.

## References

- Albrecht, T.J., Foster, V.L., Dickinson, A.L., and Debever, J.M. (1989). Triathletes: Exercise parameters measured during bicycle, swim bench and treadmill testing [Abstract]. *Med. Sci. Sports Exerc.* 18(Suppl): S86.
- Anderson-Jones, R., Houmard, J.A., Kobe, R.W., Hortobagyi, T., Bruno N.J., Wells, J.M., and Shinebarger, M.H. (1992). Effects of taper on swimm power, stroke distance, and performance. *Med. Sci. Sports Exerc.* 24: 1141-1146.
- Astrand, P.O., and Rodahl, K. (1970). *Textbook of Work Physiology*. New York: McGraw-Hill.
- Beaver W.L., Wasserman, K., and Whipp B.J. (1986). A new method for detecting anaerobic threshold by gas exchange. *J. Appl. Physiol.* 60: 2020-2027.
- Bonsignore, M.R., Morici, G., Abate, P., Romano, S., and Bonsignore, G. (1998). Ventilation and entrainment of breathing during cycling and running in triathletes. *Med. Sci. Sports Exerc.* 30: 239-245.
- Bunc, V., Heller, J., Sprynarova, S., and Zdanowicz, R. (1987). Ventilatory threshold in various groups of highly trained athletes. *Int. J. Sports Med.* 8: 275-280.
- Burke, E.R. (1980). Physiological characteristics of competitive cyclists. *Physician Sportsmed.* 8: 79-84.
- Clausen, J.P., Klausen, K., Rasmussen, B., and Trap-Jensen, J. (1973). Central and peripheral circulatory changes after training of the arms or legs. *Am. J. Physiol.* 225: 675-682.
- Coyle, E.F., Feltner, M.E., Kautz, S.A., Hamilton, M.T., Montain, S.J., Baylor, A.M., Abraham, L.D., and Petrek, G.W. (1991). Physiological and biomechanical factors associated with elite endurance cycling performance. *Med. Sci. Sports Exerc.* 23: 93-107.
- Delistraty, D.A., and Noble, B.J. (1987). Specificity in runners, triathletes, and swimmers [Abstract]. *Med. Sci. Sports Exerc.* 19: S70.

- Folinsbee, L.J., Wallace, E.S., Bedi, J.F., and Horvath, S.M. (1983). Exercise respiratory pattern in elite cyclists and sedentary subjects. *Med. Sci. Sports Exerc.* 15: 503-509.
- Foster, C., Hector, R., Welsh, M., Schraeger, M., Green, M.A., and Snyder, A.C. (1995). Effects of specific versus cross training on running performance. *Eur. J. Appl. Physiol.* 70: 367-372.
- Hagan, R.D., Smith, M.G., and Gettman, L.R. (1981). Marathon performance in relation to maximal aerobic power and training indices. *Med. Sci. Sports Exerc.* 13: 185-189.
- Hagberg, J.M., Giese, M.D., and Schneider, R.B. (1978). Comparison of three procedures for measuring  $\dot{V}O_{2max}$  in competitive cyclists. *Eur. J. Appl. Physiol.* 39: 47-52.
- Hue, O., Le Gallais, D., Chollet, D., Boussana, A., and Préfaut, C. (1998). The influence of prior cycling on biomechanical and cardiorespiratory response profiles during running in triathletes. *Eur. J. Appl. Physiol.* 77: 98-105.
- Kohrt, W.M., Morgan, D.W., Bates, B., and Skinner, J.S. (1987). Physiological responses of triathletes to maximal swimming, cycling and running. *Med. Sci. Sports Exerc.* 19: 51-55.
- Korkia, P.K., Tunstall-Pedoe, D.S., and Maffuli, N. (1994). An epidemiological investigation of training injury patterns in british triathletes. *Br. J. Sp. Med.* 28: 191-196.
- Krebs, P.S., Zinkgraf, S., and Virgilio, S.J. (1986). Predicting competitive bicycling performance with training and physiological variables. *J. Sports Med. Phys. Fitness* 26: 323-330.
- Kreider, R.B. (1988). Ventilatory threshold in swimming, cycling and running in triathletes. *Int. J. Sports Med.* 9: 147-148.
- Lucia, A., Pardo, J., Durantez, A., Hoyos, J., and Chicharro, J.L. (1998). Physiological differences between professional and elite road cyclists. *Int. J. Sports Med.* 19: 342-348.
- Martin, D.E., Vroon, D.H., May, D.F., and Pilbeam, S.P. (1986). Physiological changes in elite male distance runners training for Olympic competition. *Physician Sports. Med.* 14: 152-171.
- Miura, H., Kitagawa, K., and Ishiko, T. (1997). Economy during a simulated laboratory test triathlon is highly related to Olympic distance triathlon. *Int. J. Sports Med.* 18: 276-280.
- Mutton, D.L., Loy, S.F., Rogers, D.M., Holland, G.J., Vincent, W.J., and Heng, M. (1993). Effect of run vs combined cycle/run training on  $\dot{V}O_{2max}$  and running performance. *Med. Sci. Sports Exerc.* 25: 1393-1397.
- O' Shea, P. (1991). The science of cross training: Theory and application for peak performance. *J. Strength Condit. Res.* 12: 40-44.
- O'Toole, M.L. (1989). Training for ultraendurance triathlon. *Med. Sci. Sports Exerc.* 21(Suppl): S209-S213.
- O'Toole, M.L., and Douglas, P.S. (1995). Applied physiology of triathlon. *Sports Med.* 19: 251-267.
- O'Toole, M.L., Douglas, P.S., and Hiller, W.D. (1989). Applied physiology of a triathlon. *Sports Med.* 8: 201-225.
- Pannier, J.L., Vrijens, J., and Van Cauter, C. (1980). Cardiorespiratory responses to treadmill and bicycle exercise in runners. *Eur. J. Appl. Physiol.* 43: 243-251.
- Pechar, G.S., McArdle, W.D., Katch, F.I., Magel, J.R., and DeLuca, J. (1974). Specificity of cardiorespiratory adaptation to bicycle and treadmill running. *J. Appl. Physiol.* 36: 753-756.

- Powers, S.K., Dodd, S., Deason, R., Byrd, R., and McKnight, T. (1983). Ventilatory threshold, running economy and distance running performance of trained athletes. **Res. Q. Exerc. Sport** 54: 179-182.
- Roalstad, M.S. (1989). Physiological testing of the ultraendurance triathlete. **Med. Sci. Sports Exerc.** 21(Suppl): S200-S204.
- Robinson, D.M., Robinson, S.M., Hume, P.A., and Hopkins, W.G. (1991). Training intensity of elite male distance runners. **Med. Sci. Sports Exerc.** 23: 1078-1082.
- Schneider, D.A., Lacroix, K.A., Atkinson, G.R., Troped, P.J., and Pollack, J. (1990). Ventilatory threshold and maximal oxygen uptake during cycling and running in triathletes. **Med. Sci. Sports Exerc.** 22: 257-264.
- Simon, J., Young, J.L., Blood, D.K., Segal, K.R., Case, R.B., and Gutin, B. (1986). Plasma lactate and ventilatory thresholds in trained and untrained cyclists. **J. Appl. Physiol.** 60: 777-781.
- Sleivert, G.G., and Rowlands, D.S. (1996). Physical and physiological factors associated with success in the triathlon. **Sports Med.** 22: 8-18.
- Sleivert, G.G., and Wenger, H.A. (1993). Physiological predictors of short-course triathlon performance. **Med. Sci. Sports Exerc.** 25: 871-876.
- Spiro, S.G. (1977). Exercise testing in clinical medicine. **Br. J. Dis. Chest** 71: 145-172.
- Tanaka, K., Matsuura, Y., Matsuzaka, A., Hirakoba, K., Kumagai, S., Sun, S.O., and Asano K. (1984). A longitudinal assessment of anaerobic threshold and distance-running performance. **Med. Sci. Sports Exerc.** 16: 278-282.
- Trappe, T.A., Gastadelli, A., Jozsi, A.C., Troup, J.P., and Wolfe, R.R. (1997). Energy expenditure of swimmers during high volume training. **Med. Sci. Sports Exerc.** 29: 950-954.
- Wasserman, K., Whipp, B.J., Koyal, S.N., and Beaver, W.L. (1973). Anaerobic threshold and respiratory gas exchange during exercise. **J. Appl. Physiol.** 35: 236-243.
- Wilber, R.L., Zawadzki, K.M., Kearney, J.T., Shannon, M.P., and Disalvo, D. (1997). Physiological profiles of elite off-road and road cyclists. **Med. Sci. Sports Exerc.** 29: 1090-1094.
- Withers, R.T., Sherman, W.M., Miller, J.M., and Costill, D.L. (1981). Specificity of the anaerobic threshold in endurance trained cyclists and runners. **Eur. J. Appl. Physiol.** 47: 93-104.

*Received June 15, 1999; accepted in final form January 7, 2000*