MED SPORT 1997;50:209-16

Ventilatory threshold and maximal oxygen uptake during cycling and running in duathletes

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Background. Duathlon, an emerging sport discipline, is an endurance competition based on a sequence without interruption of running, cycling and again running fractions. The performance in duathlon, as well as triathlon, depends on the ability of the athlete to effect the three competition fractions without creating fatiguing levels which would inevitably cause a decrease of the performance in the following fractions. Currently there are no studies which have examined the relation between ventilatory threshold (T_{vent}) and maximal oxygen uptake ($\dot{V}O_{2max}$) in the cyclists and the runners comparing them with the ones of the athletes who train and compete in duathlon. Therefore the main aim of the present study has been the following ones:

1) the identification of the relationship between T_{vent} and $\dot{V}O_{2max}$ in eight élite duathletes for cycling and running and the comparison of said relationship with the one found in cyclists or runners in maximal trials with cycloergometer and on the treadmill.

2) Moreover it has been carried out an analysis of the modification of the physiological parameters through the laboratory simulation of the commitment faced in a duathlon competition by a top duathlete (Case Report).

Methods. The research methods have been the following:

a) maximal incremental test—till exhaustion—on treadmill and cycloergometer carried out on eight duathletes in different days and with an interval of no more than seven days between one trial and the other;

b) incremental exhaustion test carried out an a top duathlete on cycloergometer after 5 km of running; incremental exhaustion test on treadmill after 5 km of running and 30 km of cycling.

Results. The study has show, through its data, that $\dot{V}O_{2max}$ recorded in the duathletes during running and cycling was inferior to the values recorded for triathletes. For the duathletes, $\dot{V}O_{2max}$ obtained with running was higher than the value obtained with cycling. The ventilatory threshold (T_{vent}) recorded in duathletes was lower than the value reported for élite runners but comparable with the one reported for race cyclist, duly endurance trained.

Conclusions. These data can be explained with the different training methods for duathletes, both as far as quantity and quality are concerned, in comparison with race top athletes in the single disciplines confirming that the fit answers to the endurance exercise in the single sport are, in par, a function of motion schemes specific for that training,

Key words: Duathlete - Anaerobic threshold - Ventilatory threshold - Maximal oxygen uptake.

The duathlon, an emerging sports discipline, is an endurance competition, based on running, cycling and running in that respective order. Performance in the duathlon, as in the triathlon, depends on the athlete's capability to carry out the three successive events without accumulating fatigue, which could affect his performance in the following fraction. A successful duathlete should therefore have an extremely efficient aerobic metabolism

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TABLE I.—*General physical characteristics, duathlon experience and training regimen data for eight male duathletes.*

	Age (yrs)	Weight (kg)	Height (cm)	Duathlon experience (yrs)	Duathlon completed (yrs)	Mean training distances (km/wk)	
						run	bike
	34	72.5	181	2	12	80	300
	33	71.7	181.6	3	22	92	340
	32	62.5	172.7	3	18	88	240
	41	83.4	189	3	14	75	280
	38	72.1	177.8	3	12	72	320
	28	68.4	176	2	20	90	280
	29	66.2	175	2	16	86	300
	36	62.8	174	3	24	76	240
Means±SD	33.8±4.39	69.95±6.74	178.4±5.33	2.625±0.518	17.25±4.53	82.4±7.6	297.5±35.36

based on a well developed oxygen transportation and utilisation system, and consequently the ability to produce valuable energy for prolonged periods of time without accumulating metabolic acidosis.

More is the aerobic metabolism efficiency, less is the utilisation of the carbohydrates as energy source. Thus, the intensity of exercise has to be decided in function of the race distance to avoid early muscle glycogen depletion.

Maximal oxygen uptake ($\dot{V}O_{2max}$) is generally considered to be a useful index of good performance in endurance activities when subjects have different $\dot{V}O_{2max}$.[1, 2]

The anaerobic threshold has been studied as one of the many factors, besides $\dot{V}O_{2max}$, which could contribute to success in endurance competitions.[2, 3] Several studies confirm that anaerobic threshold could be a critical factor in determining running pace.[4]

Powers *et al.*[1] confirmed that oxygen uptake measured at the anaerobic threshold was a better indicator than $\dot{V}O_{2max}$ to predict performance in long distance runners. Few studies have examined the relationship between $\dot{V}O_{2max}$ and anaerobic threshold during running and cycling in a duathlon for athletes who train and compete in these two endurance sports, for each of which the biomechanics as well as the muscles used are different.[1, 3-8]

In conclusion the main issues of this research were as follows:

1) The definition of the relationship between $\dot{V}O_{2max}$ and T_{vent} in cycling and running, in reference to a high-level duathlete compared to athletes of one or other of the disciplines.

2) The modification of the physiological parameters investigated ($\dot{V}O_{2max}$ and T_{vent}) in the duathlete by simulating race conditions in the laboratory, in order to evaluate the performance of the "human machine" during the various transition phases—from running to cycling to running—to document eventual worsening in performance related parameters.

Methods

After written informed consent was obtained, eight male duathletes were tested during cycle ergometry and treadmill running. All the athletes were actively training and competing in duathlons during the five-week testing period. The general physical characteristics, duathlon experience and training regimen data for each subject are presented in Table I. The athletes had been training for the duathlon for an average of 2.625 yrs and had completed a mean of 17.25 duathlons of varying distances. Average training distances per week were 82.4 km running and 287.5 km cycling. Two of the eight duathletes were professional competitors. Each of the

TABLE II.—*Maximum metabolic and cardiorespiratory values obtained during incremental cycle ergometry and treadmill running for eight male duathletes.*

Variables	Cycle ergometer	Treadmill running
$\dot{V}O_{2max}$ (l·min^{-1})	4.65±0.78	5.02±0.89
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	66.3±9.0	71.4±10.3
HR max (beats·min^{-1})	176±10.0	179±8.0
R	1.15±0.4	1.18±0.7
Ve max (l·min^{-1})	145.3±18.7	142.4±19.2
Vt (l)	2.94±0.56	2.85±0.48
fr (breaths·min^{-1})	60.1±10.6	57.9±9.0
(HLa) (mmol)	10.4±2.6	10.8±2.2
Power output (W)	360.0±60.0	400.0±40.0

Values are mean±& L. R is the maximum respiratory exchange ratio obtained during incremental exercise. Vt indicated the tidal volume measured during maximal exercise. The respiratory frequency determined during maximal exercise is represented as fr. (HLa) is the peak lactate concentration measured two minutes after reaching volitional exhaustion.

TABLE III.—*Metabolic and cardiorespiratory values measured at ventilatory threshold for the cycle ergometer and treadmill running.*

Variables	Cycle ergometer	Treadmill running
VO_2 (l·min^{-1})	3.17±0.32	3.67±0.33
VO_2 (ml·kg^{-1}·min^{-1})	53 – 43.9±4.3	50.9±6.8 – 60
%$\dot{V}O_{2max}$	68.8±3.7	73.9±6.6
Ve (l·min^{-1})	82.6±9.1	99.7±9.3
Vt (l)	2.86±0.52	2.50±0.47
fr (breaths·min^{-1})	28.1±5.1	40.7±9.0
HR (beat·min^{-1})	152.0±8.0	158.0±9.0
% HR max	80.4±3.2	86.0±4.2

Values are means±SD.

eight duathletes performed a continuous incremental test to a volitional exhaustion on a cycle ergometer (Technogym-Bikerace) and on a treadmill (Technogym-Runrace).

The exercise protocols were performed on separate days, with no more than seven between tests. Exercise protocols were constituted by two minutes steps with 40 watt of increment on the cycloergometer, and two minutes steps with 1 km of increment on the treadmill.

The $\dot{V}O_{2max}$ was determined when the $\dot{V}O_2$ uptake didn't increase in two subsequent steps and estimated at RQ of 1.15.

Capillary blood samples for the determination of lactate concentration were obtained two minutes after reaching volitional exhaustion.

The two minutes recovery period was passive.

This methodology has been chosen accordingly to Donald A. Schneider *et al.*[8] and also not to effect the evolution of testing. It is also to be considered that during the first 2 minutes of passive recovery blood lactate accumulation is maximal.

During each exercise test, the subject breathed through a mouthpiece attached to a turbine device. The respired gas was continuously sampled by a Sensor Medics 2900 C metabolic cart for breath—by breath determination of metabolic and ventilatory variables. The use of non-invasive techniques to determine the ventilatory threshold has been described by Wasserman *et al.*[9]

The ventilatory threshold was indicated as the work-rate or $\dot{V}O_2$ at which the ventilatory equivalent for oxygen ($V_E/\dot{V}O_2$) increased without a marked rise in the ventilatory equivalent for carbon dioxide ($V_E/\dot{V}CO_2$). The anaerobic ventilatory threshold (T_{vent}) is one of the objective measurements which indicated a circulatory-metabolic limitation to exercise.

Results

Maximum metabolic and cardiorespiratory values obtained during cycle ergometry and treadmill running are presented in Table II.

Table III presents the mean and standard deviation values for the metabolic and cardiorespiratory values measured at the T_{vent} for both modes of exercise.

Table IV Case Report presents the principal physiological parameters of the Italian champion, related to a racing situation, to investigate power output at the transition from running to cycling and back to running again.

TABLE IV.—*Case report. Principal physiological parameters in the duathlon champion under racing conditions, investigating power output at the transition from running to cycling and back to running.*

Age	Weight	Height	Duathlon experience	Duathlon completed	Mean training distances (km.wk)
34	172.5	181	2 yrs	12	run 80 cycle 300

Variables	Cycle ergometre	Treadmill running	Cycle ergometre (after 5 km run)	Treadmill running (after 5 km run and 30 km cycle)
$\dot{V}O_{2max}$ (l min-1)	5.122	5.435	4.959	4.810
$\dot{V}O_{2max}$ (ml kg-1 min-1)	72.84	76.23	69.08	66.97
$\dot{V}O_2$ T_{vent}	61.91	67.08	56.64	50.22
%$\dot{V}O_{2max}$	85%	885%	82%	75%
HRmax	168	176	165	172
HR T_{vent}	158	166	155	160
Power output (W)/Speed km·h-1	420	22	380	19
Power Tvent/Speed km h-1	360	19	310	18

The first running and cycling sections were performed at anaerobic threshold speed.

Discussion

Maximal oxygen uptake has been measured and reported for most groups of élite athletes who train and compete in single sport such as running or cycling.[1 3 4 6 10-13]

The mean running $\dot{V}O_{2max}$ of 71.1 ml· kg-1· min-1 compared favourably with the values previously reported for highly trained male distance runners.[1 3 11 14]

The running $\dot{V}O_{2max}$ for the duathletes was 10% less than the value of 79.3 ml·kg-1·min-1 reported by Martin *et al.*[9] for nine élite male runners training for the 1984 Olympic Games.

Moreover, the mean $\dot{V}O_{2max}$ value of 66.3 ml·kg-1·min-1 for cycle ergometry was 6% less than the value of 71.1 ml·kg-1·min-1 reported by Folinsbee *et al.*[6] for seven élite cyclist and by myself on professional cyclist.

The cycling $\dot{V}O_{2max}$ for the duathletes was 10% less than the $\dot{V}O_{2max}$ of 74.0 ml·kg-1·min-1 reported by Burke for 23 members of the US national Cycling team.[10] Thus these differences are significant in determining performance capabilities in single sport competitors, they should be considered relatively small for athletes training in a multidisciplines event like duathlon and triathlon, considering that the duathletes trained less in any one sport than single-sport athletes. Nonetheless, the achievement of high $\dot{V}O_{2max}$ values may demonstrate a true cross-training effect.

Previously reported $\dot{V}O_{2max}$ values for running in male triathletes ranged from 57.4 to 72 ml·kg-1·min-1, while the values reported for cycling ranged between 54.4 and 66.7 ml·kg-1·min-1.

Thus, the duathletes in the present study had average running and cycling $\dot{V}O_{2max}$ values that were greater than those previously reported for male triathletes.

This could suggest that more is the number of disciplines, lower is the $\dot{V}O_{2max}$ for any single sport.

Maximal oxygen uptake values are usually highest when the largest muscle mass in used in the test.[15 16]

Researchers have found that the $\dot{V}O_{2max}$ for cycle ergometry is typically 8-11% less than the value obtained for treadmill running.[15 16]

These relationships have been shown to change significantly with endurance training.[3 7] Most previous studies have focused on athletes who train and compete in only one sport. For example, Hagberg *et al.*[7] observed that competitive cyclist had a $\dot{V}O_{2max}$ for cycling that was about 4% higher than for treadmill running. A study by Withers *et al.*[3] found that competitive male cyclist had a slightly higher $\dot{V}O_{2max}$ on the cycle ergometer than on the treadmill, whereas endurance trained runners had greater $\dot{V}O_{2max}$ values on the treadmill when compared with the cycle ergometer.

These studies suggest that adaptive responses to exercise in single-sport are in part a function of specific muscle groups recruited in training.

The running $\dot{V}O_{2max}$ achieved by the duathletes in the present study was significantly higher than the maximal aerobic capacity obtained in cycle ergometry.

The duathletes in the present study demonstrated a 7% running to cycling $\dot{V}O_{2max}$ difference.

This occurred even though cycling was the primary mode of training in terms of distance for week (82.5 km running *vs* 297.5 cycling). Although this finding is in contrast with the overabove studies, it can be depending on the training intensity in the two disciplines. The distance itself cannot be considered as the only significative training parameters to improve $\dot{V}O_2$.

Many researchers have examined the anaerobic threshold in male athletes who train and compete in only one sport such as running or cycling.[1 3 4 6 11 13]

When oxygen uptake measured at the anaerobic threshold is expressed as a percentage of $\dot{V}O_{2max}$ values reported for distance runners ranged from 70 to 88%.

Some recent investigations reported that the T_{vent} occurred at 88.2% in élite distance runners [13] and at 86.7% in marathon runners.[6]

Thus, the mean running T_{vent} value of 73.9% of $\dot{V}O_{2max}$ for the duathletes in the present study was lower than recently reported values for élite distance runners and marathoners.

This may be attributed in part to the large difference in running volume during training between élite distance runners and the duathletes.

Élite distance runners typically run between 140-200 km for week, whereas the duathletes in the present study only run an average of 82.5 km for week.

However, it is also possible that élite runners train at a higher exercise intensity or do more interval training than duathletes.

The duathletes had a mean T_{vent} for cycling of 68.8% of $\dot{V}O_{2max}$ which is nearly identical to the values of 66.3% of $\dot{V}O_{2max}$ reported by Whiters *et al.* for 10 endurance trained cyclist.

In conclusion, the duathletes taken into account by the present study, showed T_{vent} values which were comparable with the ones presented for competitive male cyclists, whereas the T_{vent} values of running were lower than the ones of compared élite distance runners.

All that could be explained by the specificity type of the training carried out by duathletes in comparison with the kind of training made by cyclist.

In fact, competitive cyclists include in their training many intensity variations which, very frequently, involve a physio-logic-metabolic commitment close to the $\dot{V}O_{2max}$ values consumption.

Differently, the duathletes train almost constantly in cycling around values next to those of the anaerobic threshold for prolonged times.

One evicts that from the particular characteristics of the duathlon competition where, the cycle fraction, foreseen in between the two running phases, takes place without the possibility of taking advantage of drafting so the cardiocircolatory and metabolic commitment corresponds with the one of a 40 km chronometer race in which the best performance is reached by maintaining the exercise intensity around anaerobic threshold values.

The lower values of average T_{vent} in duathletes in comparison with élite runners and marathon racers in running are imputable to the incapacity of sustaining prolonged trainings close to the anaerobic threshold both because of the reduce distance in kilometres and because of the muscular tiredness following from the almost daily double training which conditions much more the performance in running in comparison with cycling.

These data, which currently have no literature terms of comparison, will be, for sure, likely to change when duathlon enlists high-level athletes from the single sports, such as running and cycling and subsequently fits them specifically for the double discipline.

Case report

Now, I will quickly comment the modification of physiological parameters of the Italian Champion of Duathlon under racing condition, investigating power output at the transition from running to cycling and back to running.

It is interesting to note how the decrease of $\dot{V}O_{2max}$ and T_{vent} appears limited during the bicycle stage but is noticeably apparent during the last treadmill stage, after 5 km running and 30 km cycling. The $\dot{V}O_{2max}$ on cycloergometre test after 5 kilometres of submaximal running (at a corresponding intensity to the value of the anaerobic threshold), falls by only 5% in respect to the value obtained at rest, whilst the T_{vent} falls by only 3%. The $\dot{V}O_{2max}$ and the T_{vent} however, when recorded on the treadmill test after 5 km of submaximal running and 30 km of cycling at high intensity, showed a fall of only 13% in respect to the value obtained on the treadmill test starting from resting condition.

Such data can only be interpreted in a plausible way assuming that the duathlete has carried out the test simulating the strategy utilised in duathlon races. This strategy consist in the first part of the race being run at an intensity that corresponds with the value of the heart rate target zone of the anaerobic threshold. In the second part, the cycling phase, the duathlete uses practically all his aerobic potential, from which he derives an utility of elevated percentage of the maximum oxygen uptake, and in consequence with a vent little less than that recorded in the test of the cycloergometre effected at rest. The notable fall of the $\dot{V}O_{2max}$ and of the relative T_{vent} in the last phase of the race in respect to the value recorded in the single test on the treadmill at rest must be attributed to, not only a general exhaustion, but also to multiple factors, amongst which an example is the decrease in energy resources, the reduction in plasmatic volume, biochemical and structural modification in the duathlete after cycling phase, that represent the true factor and thus limiting the performance in multiple sport such as duathlon.[17 18]

The most important factor of the decrease in energy cost of running could be related with biomechanicals changes. Running economy is influenced by biomechanical factors such as stride length, body centre of mass excursion, impact force, trunk angle of inclination. Several recent data indicate that muscle fatigue and neurosensorial factors influence negatively the biomechanical pattern at the end of a duathlon.

Riassunto

Soglia anaerobica ventilatoria e massimo consumo di ossigeno durante ciclismo e la corsa a piedi nei duatleti

Introduzione. Il duathlon, disciplina sportiva emergente, è una competizione di endurance basata sul susseguirsi senza interruzione di frazioni di corsa a piedi, ciclismo e nuovamente corsa a piedi.

La prestazione nel duathlon, come del resto anche nel triathlon, dipende dalla capacità dell'atleta di effettuare le tre frazioni di gara senza creare livelli di affaticamento che inevitabilmente comporterebbero un calo della performance nella frazione successiva.

Non esistono al momento studi che hanno esaminato le relazioni tra soglia ventilatoria (T_{vent}) e massimo consumo di ossigeno ($\dot{V}O_{2max}$) nei ciclisti e nei podisti comparandole a quelle di atleti che si allenano e che gareggiano in competizioni di duathlon.

Obiettivo. Pertanto lo scopo principale del presente studio è stato:

1) l'identificazione della relazione tra T_{vent} e $\dot{V}O_{2max}$ in 8 duatleti di élite per il ciclismo e la corsa a piedi e confronto di detta relazione con quella riscontrata in ciclisti o podisti in prove massimali al cicloergometro e su nastro trasportatore;

2) inoltre è stata effettuata un'analisi delle modificazioni dei parametri fisiologici attraverso la simulazione in laboratorio dell'impegno affrontato in una gara di duathlon da un atleta di vertice (Case Report).

Metodi. I metodi della ricerca sono stati i seguenti:

a) test incrementale massimale ad esaurimento su nastro e su cicloergometro condotti in giorni diversi e con un intervallo di non più di 7 giorni tra una prova e l'altra in 8 duatleti;

b) test incrementale ad esaurimento al cicloergometro dopo 5 km di corsa a piedi; test incrementale ad esaurimento su nastro rotante dopo 5 km di corsa e 30 km di ciclismo in 1 duatleta di vertice.

Risultati. I dati dello studio hanno dimostrato che la $\dot{V}O_{2max}$ registrata nei duatleti nella corsa e nel ciclismo era inferiore ai valori riportati per atleti di alto livello che competono nelle singole discipline, mentre era superiore ai valori riportati per atleti di triathlon.

Per i duatleti la $\dot{V}O_{2max}$ ottenuta nella corsa era superiore al valore ottenuto nel ciclismo.

La soglia ventilatoria (T_{vent}) riscontrata nei duatleti era inferiore al valore riportato per atleti corridori d'élite, ma comparabile a quella riportata per ciclisti agonisti allenati alla resistenza.

Conclusioni. Questi dati possono essere spiegati con la diversa metodologia di allenamento nei duatleti, sia per quantità che per qualità, rispetto agli atleti competitivi di alto livello nelle singole discipline, confermando che le risposte adattative all'esercizio di resistenza nel singolo sport sono in parte una funzione di schemi di movimento specifici per quell'allenamento.

Parole chiave: Duatleta - Soglia anaerobica - Soglia ventilatoria - Massimo consumo di ossigeno.

Resumen

Umbral anaeróbico de ventilación y consumo máximo de oxígeno durante el ciclismo y la carrera pedestre en los duathletas.

Introducción. El duathlon, una nueva disciplina deportiva, es una competición de endurance basada en la sucesión, sin interrupciones, de fracciones de carrera pedestre, ciclismo y nuevamente carrera pedestre.

La prestación en el duathlon, como también en el triathlon, depende de la capacidad del atleta de efectuar las tres fracciones de competición sin crear un nivel de fatiga que inevitablemente comportaria una reducción de la prestación en la fracción siguiente.

Hasta la fecha no existen estudios que hayan examinado las relaciones entre el umbral de ventilación (T_{vent}) y el consumo máximo de oxígeno ($\dot{V}O_{2max}$) en los ciclistas y en los podistas comparándolas con las de atlelas que se entrenan y participan en competiciones de duathlon.

Objetivo. Por lo tanto, el objeto principal de este estudio ha sido:

1) la identificacion de la relación entre T_{vent} y $\dot{V}O_{2max}$ en 8 duathletas de élite para el ciclismo y la carrera pedestre y la comparación de esta relación con la observada en ciclistas o podistas en pruebas maximales con cicloergómetro y en cinta transportadora;

2) asimismo, se ha efectuado un análisis de las modificaciones de los parámetros fisiológicos a través de la simulación en laboratorio de los esfuerzos realizados en una competición de Duathlon por un atleta de cumbre (Case report).

Métodos. Los métodos de la investigación han sido los siguientes:

a) pruebas maximales de incremento hasta el agotamiento sobre cinta y cicloergómetro realizados en días distintos y con intervalo no superior 7 días entre una prueba y otra en 8 duathletas;

b) prueba de incremenlo hasta el agotamiento en el cicloergómetro después de 5 km de carrera pedestre; prueba de incremento hasta el agotamiento sobre cinta rotativa después de 5 km de carrera y 30 de ciclismo en 1 duathleta experto.

Resultados. Los datos de la investigación han demostrado que la $\dot{V}O_{2max}$, registrada en los duathletas en la carrera y en el ciclismo era inferior a los valores observados en atletas de alto nivel que compiten en una sola de las disciplinas, mientras que era superior a los valores observados en los atletas de triathlon.

Para los duathletas la $\dot{V}O_{2max}$ obtenida en la carrera era superior al valor obtenido en el ciclismo.

El umbral de ventilación (T_{vent}) observado en los duathletas era inferior al valor observado en los atletas podistas de élite, pero se podía comparar con el observado en los ciclistas profesionales entrenados a la resistencia.

Conclusiones. Estos datos se pueden explicar con el método de entrenamiento distinto de los duathletas, tanto en materia de cantidad como de calidad, respecto a los atletas competitivos de alto nivel en cada disciplina, confirmando que las respuestas de adaptación al ejercicio de resistencia en un solo deporte son parcialmente una función de esquemas de movimientos específicos para ese tipo de entrenamiento.

Palabras clave: Duathleta - Soglia anaerobica - Soglia ventilatoria - Massimo consumo di ossigeno.

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