Metabolic and cardioventilatory responses during a graded exercise test before and 24 h after a triathlon

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Abstract Previous studies have reported respiratory, cardiac and muscle changes at rest in triathletes 24 h after completion of the event. To examine the effects of these changes on metabolic and cardioventilatory variables during exercise, eight male triathletes of mean age 21.1 (SD 2.5) years (range 17–26 years) performed an incremental cycle exercise test (IET) before (pre) and the day after (post) an official classic triathlon (1.5-km swimming, 40-km cycling and 10-km running). The IET was performed using an electromagnetic cycle ergometer. Ventilatory data were collected every minute using a breath-by-breath automated system and included minute ventilation ($\dot{V}_E$), oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio, ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$) and for carbon dioxide ($\dot{V}_E/\dot{V}CO_2$), breathing frequency and tidal volume. Heart rate (HR) was monitored using an electrocardiogram. The oxygen pulse was calculated as $\dot{V}O_2$/HR. Arterialized blood was collected every 2 min throughout IET and the recovery period, and lactate concentration was measured using an enzymatic method. Maximal oxygen uptake ($\dot{V}O_{2\max}$) was determined using conventional criteria. Ventilatory threshold (VT) was determined using the V-slope method formulated earlier. Cardioventilatory variables were studied during the test, at the point when the subject felt exhausted and during recovery. Results indicated no significant differences ($P > 0.05$) in $\dot{V}O_{2\max}$ [62.6 (SD 5.9) vs 64.6 (SD 4.8) ml · kg^{-1} · min^{-1}], VT [2368 (SD 258) vs 2477 (SD 352) ml · min^{-1}] and time courses of $\dot{V}O_2$ between the pre- versus post-triathlon sessions. In contrast, the time courses of HR and blood lactate concentration reached significantly higher values ($P < 0.05$) in the pre-triathlon session. We concluded that these triathletes when tested 24 h after a classic triathlon displayed their pre-event aerobic exercise capacity, bud did not recover pre-triathlon time courses in HR or blood lactate concentration.

Key words Maximal oxygen uptake · Ventilatory threshold · Blood lactate · Incremental exercise · Triathlon

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Introduction

The triathlon consists of three consecutive endurance events, swimming, cycling and running, and thus requires high aerobic capabilities. Triathletes have been reported to exhibit high values of maximal oxygen uptake ($\dot{V}O_{2\max}$; Dengel et al. 1989; Kohrt et al. 1989) and ventilatory threshold (VT; Roalstad 1989; Schneider et al. 1990). Numerous physiological changes have been observed in triathletes during or at the end of the race, particularly metabolic (Farber et al. 1987; Lamon-Fava et al. 1989; Nagao et al. 1984), hormonal (Sagnol et al. 1990), enzymatic (Fellmann et al. 1988), haematological (Long et al. 1990; O'Toole et al. 1988), hydro-electrolytical (Hiller 1989; Laird 1989), biochemical (Jurimae et al. 1989), respiratory (Hill et al. 1991), cardiovascular and thermal (Kreider et al. 1988).

Recently, De Vito et al. (1995) have reported the impairment of running $\dot{V}O_{2\max}$ and VT after the swimming and cycling segments of a simulated triathlon. The outcomes of these acute effects of the triathlon have been studied during the recovery period and during the days following the event. Douglas et al. (1987) have reported alterations in systolic and diastolic performance of the left ventricle. Hill et al. (1991) have reported significantly below-baseline forced expiratory volumes in 1 s. Farber et al. (1991) have reported a maximal rise in creatine phosphokinase on the day after the triathlon, and have noted that the enzyme increase was still apparent 6 days later.

We postulated that the changes in respiratory, cardiac and muscle function that have been reported at rest in triathletes on the day following completion of the event would impair their oxygen transport system and, consequently, would modify the time courses of their oxygen uptake ($\dot{V}O_2$) and cardioventilatory responses during exercise. The aim of the present study was thus to compare the time courses of metabolic and cardioventilatory variables in triathletes during exercise performed before a triathlon and the day following the event.

Methods

Subjects

A group of eight male triathletes with a mean age of 21.1 (SD 2.5) years were studied (Table 1). The subjects were informed of the nature of the study and gave written consent prior to their inclusion. All the triathletes had been training intensely for more than 2 years and were studied during a period of active competition, i.e. they were training daily and participating in official triathlons every week or two.

Protocol

All the triathletes performed two laboratory tests, between 9 a.m. and 4 p.m. The first test was performed 4–6 days before the triathlon (pre), and the second was performed 22.4 (SD 2.6) h after the race (post). Each subject performed both tests at the same time of day, to minimize variation due to circadian rhythms. They were also asked to observe similar schedules of activity including meals and sleep, on both occasions. Moreover, the subjects were specifically asked not to train on the test days. Each session included a clinical examination at rest (height, mass, blood pressure, pulse rate, pulmonary and cardiac auscultation) and a cycle incremental exercise test (IET). Temperatures, barometric pressures and relative humidities during the laboratory tests were 20–22°C, 750–755 mmHg and 50%–60%, respectively.

Table 1 Anthropometric characteristics for the eight triathletes. *Placement* Finishing position out of 1500 competitors

Subjects	Age (years)	Body mass (kg)		Height (cm)	Triathlon	
		Pre	Post		Time h:min	Placement
1	26	70	70	187	1:45	14
2	20	72	71	184	1:48	29
3	21	62	62	175	1:54	50
4	22	62	61	170	1:54	52
5	21	77	77	184	1:57	79
6	20	65	66	180	2:00	92
7	17	67	67	176	2:04	173
8	22	72	72	179	2:08	233
Mean	21.1	68.3	68.2	179	1:56	–
SD	2.5	5.3	5.3	5	0:07	–

Cycle incremental exercise test

The triathletes performed a cycle IET using an electromagnetic cycle ergometer (Ergoline, Bitz, Germany). The initial warm-up power of 30 W was maintained for 3 min, and the power was then increased by steps of 30 W every minute until the subject felt exhausted (P_{max}, watts). Ventilatory data were collected every minute during IET and the following 5-min recovery (R1, R2, etc.), using a breath-by-breath automated metabolic system (CPX Medical Graphics, Minn., USA): minute ventilation ($\dot{V}_E$), $\dot{V}O_2$, carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (R), respiratory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$), respiratory equivalent for carbon dioxide ($\dot{V}_E/\dot{V}_{CO_2}$), breathing frequency (f), and tidal volume (V). Heart rate (HR) was monitored using a standard 12-lead electrocardiogram (Medical Graphics, Minn., USA). The oxygen pulse (O_2P) was calculated by dividing $\dot{V}O_2$ by HR. The achievement of at least two of the following criteria was necessary to conclude that the triathletes had reached their $\dot{V}O_{2max}$:

1. A levelling off in $\dot{V}O_2$ despite an increase in exercise intensity over the final stages of IET
2. HR within 15 beats$\cdot$min^{-1} of age predicted maximal HR (220 minus age)
3. R greater than 1.10.

VT was determined according to the V-slope method of Beaver et al. (1986). This method involves the analysis of the behaviour of $\dot{V}CO_2$ as a function of $\dot{V}O_2$ and assumes that VT corresponds to the breakpoint in the $\dot{V}CO_2$-$\dot{V}O_2$ relationship. The VT was determined automatically using an IBM computer, and the breakpoint determination was verified independently by two experienced investigators.

Blood lactate measurements

Arterialized blood samples from an ear lobe were obtained after rubbing the lobe with a vasodilating ointment (Finalgon, Boehringer, Ingelheim, Germany). The samples were collected every 2 min during IET and recovery in 150-µl heparinized glass capillary tubes (Instrumentation Laboratory Company, Mass., USA), immediately diluted in a haemolizing solution, and then stored at 4°C. The measurements were carried out within 7 days using an enzymatic method in a lactate analyser (Microzym L, SGI, Toulouse, France) according to Geyssant et al. (1985).

Triathlon

The triathletes performed an official classic triathlon consisting of 1.5 km of swimming, 40 km of cycling and 10 km of running. Event times ranged from 1 h 45 min to 2 h 08 min (Table 1). Ambient temperature was 24°C with a humidity of 55%, and water temperature was 20°C. During the race the triathletes had unrestricted access to fluids and food.

Statistical analysis

The comparison of means measured at VT and P_{max} during the IET for the pre- versus post-triathlon sessions was made using the paired samples student's t-test. The correlations between triathlon performance and both pre-triathlon VT and $\dot{V}O_{2max}$ were made using the Pearson product-moment correlation. The comparison of IET pre- versus post-triathlon time courses of metabolic and cardioventilatory responses was made using a two-way analysis of variance (ANOVA) for repeated means. In each of the two laboratory test sessions 9 min were studied: the last minute of the 3-min warm-up period, and the following 8 min of IET. The first 5 min of the recovery period were also taken into account. When statistically significant differences were identified by ANOVA, the post-hoc contrast method was used with correction for multiple comparison using the Newman-Keuls test. Statistical significance was set at $P < 0.05$

Results

The anthropometric and triathlon performance characteristics of the triathletes are reported in Table 1. The triathlon performances ranged from 1 h 45 min to 2 h 08 min [mean 1 h 56 min (SD 0 h 07 min], and indicated the triathletes were in good athletic condition. The body masses were similar before the two tests, indicating no difference in baseline state.

There was no significant correlation between performance in the triathlon and pre-triathlon VT ($r = -0.16$, $P = 0.71$) or pre-triathlon $\dot{V}O_{2\,max}$ ($r = -0.47$, $P = 0.28$). The triathletes achieved similar P_{max}, VT, and $\dot{V}O_{2\,max}$, and similar time courses of $\dot{V}O_2$ in the pre- versus post-triathlon sessions (Table 2, Fig. 1). Lastly, the triathletes exhibited similar values for cardioventilatory responses at VT and P_{max} in the two sessions, including $\dot{V}CO_2$, $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ (Table 2).

Repeated measures ANOVA revealed a significant test effect for HR (pre > post-triathlon, Fig. 2), O_2P (pre < post-triathlon, Fig. 3), and blood lactate concentrations (pre > post-triathlon, Fig. 4). In addition, a significant test × time interaction was identified for HR (pre > post-triathlon at 3, 4 and 5 min, Fig. 2), O_2P (pre < post-triathlon at 1, 5 and 9 min, Fig. 3), and blood lactate concentrations (pre > post-triathlon at 8 min of IET and 3 min of recovery, Fig. 4). Blood lactate concentration data were not analysed at 12 min because five subjects (pre) and three subjects (post) were unable to exercise at the intensity set for this time.

Discussion

The comparison of metabolic and cardioventilatory data in triathletes during incremental exercise tests performed

Table 2 Cardioventilatory values collected at the ventilatory threshold and at maximal exercise intensity (P_{max}) before (*pre*) and 1 day following a classic triathlon (*post*). *Pre* 4–6 days before the triathlon, *Post* 24 h after the triathlon, $\dot{V}_E$ minute ventilation, $\dot{V}O_2$ oxygen uptake, *R* respiratory exchange ratio, f_b breathing frequency, V_T tidal volume, *HR* heart rate, O_2P oxygen pulse

Variables	Ventilatory threshold				P_{max}			
	Pre		Post		Pre		Post	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Power output (W)	–	–	–	–	356	33	345	35
$\dot{V}_E$ ($l \cdot min^{-1}$)	55.3	6.8	54.1	7.4	137.0	14.9	135.9	13.3
$\dot{V}O_2$ ($ml \cdot min^{-1}$)	2368	258	2477	352	4254	281	4393	204
$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	35.0	5.4	36.3	4.4	62.6	5.9	64.6	4.8
R	0.92	0.06	0.90	0.04	1.19	0.09	1.17	0.07
f_b (breaths $\cdot min^{-1}$)	26.8	4.1	24.8	4.5	47.5	9.5	47.0	8.8
V_T (ml)	2086	226	2202	319	2955	455	3157	746
HR (beats $\cdot min^{-1}$)	132	12	131	7	175	7	170	6
O_2P ($ml \cdot beat^{-1}$)	17.8	1.0	18.8	2.7	24.3	1.6	25.8	1.4

No statistically significant differences were found between pre- versus post-triathlon cardioventilatory values at ventilatory threshold and P_{max}

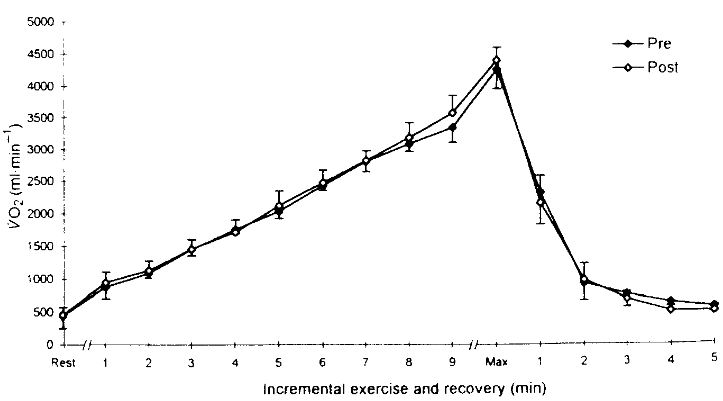

Fig. 1 Oxygen uptake ($\dot{V}O_2$: mean and SD) during incremental exercise and recovery in triathletes, before (*Pre*) and 1 day following competition (*Post*)

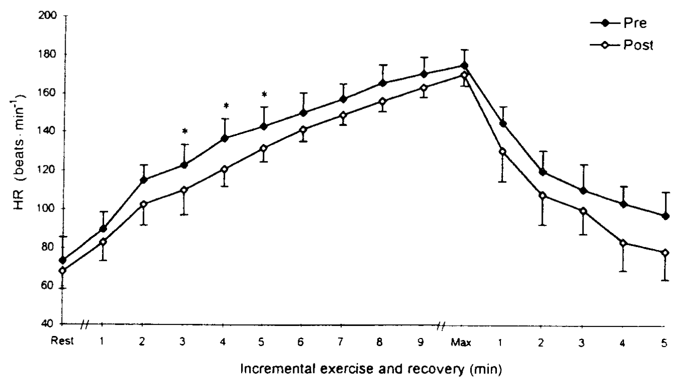

Fig. 2 Heart rate (*HR*; mean and SD) during incremental exercise and recovery in triathletes, before (*Pre*) and 1 day following competition (*Post*). **Pre* > *Post*-triathlon ($P < 0.05$)

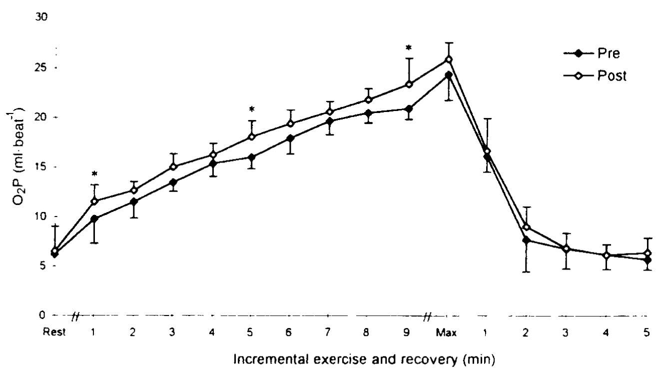

Fig. 3 Oxygen pulse (O_2P; mean and SD) during incremental exercise and recovery in triathletes, before (*Pre*) and 1 day following competition (*Post*). **Pre* < *Post*-triathlon ($P < 0.05$)

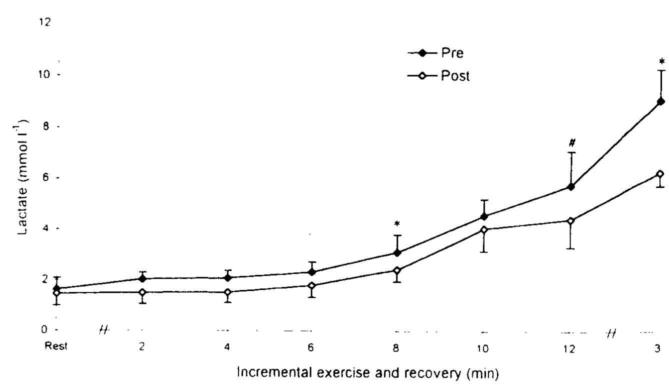

Fig. 4 Blood lactate concentration (mean and SD) during incremental exercise and recovery in triathletes, before (*Pre*) and 1 day following competition (*Post*). **Pre* > *Post*-triathlon ($P < 0.05$). #Data not analysed due to failure of five subjects (*Pre*) and three subjects (*Post*) to attain the appropriate exercise intensity at 12 min

before a classic triathlon and the day following the event showed no significant differences in either $\dot{V}O_2$ at VT and $\dot{V}O_{2\,max}$, or in the time course of $\dot{V}O_2$ during the tests. In contrast, significantly lower time courses of HR and blood lactate concentration characterized the 24-h post-triathlon incremental exercise test compared with the pre-triathlon test.

The similar body masses noted in the triathletes on the 2 test days suggested the athletes had rehydrated well 24 h after the competition, and confirmed that they were experienced athletes. The similar VT, $\dot{V}O_{2max}$ and the time courses of $\dot{V}O_2$ measured in the two IET indicated that the aerobic capabilities of the triathletes in cycling were not impaired 24 h after completion of a classic triathlon (Table 2). This result suggests that the impairment of VT and $\dot{V}O_{2max}$ which has been reported at the beginning of the running segment of a triathlon, and due to swimming and cycling fatigue (De Vito et al. 1995), was not present 24 h later, despite the respiratory, cardiac and muscle changes which have been reported in triathletes at rest on the day following completion of a race (Douglas et al. 1987; Farber et al. 1991; Hill et al. 1991). It also suggests that from the functional impairments observed at rest the assumption cannot be made that there will be impairments during exercise. This observation may explain the ability of triathletes to exercise daily at high aerobic intensity. It may also reflect the poor relationship between VT, $\dot{V}O_{2max}$ and triathlon performance noted in the present study and suggested by the wide ranges of VT (45%–64% $\dot{V}O_{2max}$) and $\dot{V}O_{2max}$ values (52.2–84.5 $ml \cdot kg^{-1} \cdot min^{-1}$) that have been reported in elite triathletes (O'Toole et al. 1989; Otto et al. 1985; Roalstad 1989; Schneider et al. 1990).

The similar IET performance achieved by the triathletes in the two sessions with similar $\dot{V}O_2$ time courses indicates a comparable energy cost of cycling for the pre- versus post-triathlon sessions, indicating that there was no skeletal muscle fatigue during exercise 24 h after the event. This is in contrast with reports that have been made of skeletal muscle injury at rest following a triathlon (Farber et al. 1991). Does the absence of significantly lower P_{max} and aerobic metabolism (VT, $\dot{V}O_{2max}$, and time courses of $\dot{V}O_2$) in the post-race session imply that the triathletes would have been capable of similar performances in a second triathlon 24 h after the first one? Mayers et al. (1986) have found similar $\dot{V}O_{2max}$ and VT in triathletes during an initial maximal treadmill test and in a second test performed immediately after a 45-min ride on a cycle ergometer at the exercise intensity of VT. However, the running time of the second test was significantly shorter. Thus, similar aerobic metabolism in triathletes does not imply similar time performance in the triathlon, and would suggest that aerobic capabilities are not predictive of overall competition performance in triathletes.

The significantly lower time courses of HR exhibited by the triathletes during the post-triathlon session suggested that 24 h after completion of a classic race, the catecholamine response to exercise was depressed. Douglas et al. (1987) have reported alterations in left ventricular performance during systole and diastole at the finish and during recovery after the Hawaii Ironman Triathlon. Specifically, the left ventricular dimension during diastole remained reduced after 1 day of recovery, implying an altered preload. Similarly, Niemela et al. (1984) have reported reduced fractional shortening at the finish after a 24-h race, returning to normal 2–3 days later and suggesting a depression of contractility. Sagnol et al. (1990) have investigated the late effects of a 10-h triathlon on sympatho-adrenal and dopaminergic activity and have reported a decreased release of adrenaline from the adrenal medulla for several days after the race.

Thus, the triathlon could induce a depression in baseline blood adrenaline concentrations during recovery, and the lower HR time courses observed throughout the post-race IET in the present study could have been due to a depressed adrenaline response to exercise and/or to a lower sensitivity of cardiac catecholaminergic receptors. The lower time courses of HR in association with the similar time courses of $\dot{V}O_2$ in the post-triathlon IET session led to an increase in the time courses of O_2P and indicated an increased stroke volume (SV) and/or an increased peripheral $\dot{V}O_2$ extraction. The decrease in adrenaline release reported by Sagnol et al. (1990) and the alterations in systolic and diastolic left ventricular functions reported by Douglas et al. (1987) on the day following a triathlon would suggest that an increase in $\dot{V}O_2$ extraction in muscle is more likely to be involved in the time course in $\dot{V}O_2$ maintained in the post-triathlon than an increased SV.

Lastly, the significantly lower time courses in blood lactate concentration exhibited by the triathletes during the post-triathlon session implied changes in the metabolism of blood lactate during exercise 24 h after completion of a classic triathlon. This finding must surely in great part be due to a decrease in reserves of glycogen in skeletal muscle, as is generally acknowledged. However, it could also be in association with the lower adrenaline response to exercise suggested in these triathletes by their lower HR time courses. Indeed, blood lactate concentrations have been found to be correlated with blood adrenaline concentrations during exercise (Brooks 1991). Another explanation may be the greater use of triglycerides as a muscle energy substrate during recovery following completion of a race (Farber et al. 1991), or the greater use of muscle lactate by type I fibres, according to the lactate shuttle theory of Brooks (1991).

In conclusion, the present study showed that aerobic metabolism during exercise in triathletes, that is $\dot{V}O_2$ at VT, $\dot{V}O_{2max}$, and the time course of $\dot{V}O_2$ assessed during an incremental exercise test on the day following completion of an event, was not impaired when compared with the pre-triathlon exercise values. In contrast, the time courses of HR and blood lactate concentration during the post-triathlon incremental exercise test were decreased. This would indicate that not all the metabolic and cardioventilatory responses had recovered to the pre-competition state 24 h after the event.

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