The influence of prior cycling on biomechanical and cardiorespiratory response profiles during running in triathletes

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ORIGINAL ARTICLE

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Abstract The aim of the present study was to determine the effects of 40 km of cycling on the biomechanical and cardiorespiratory responses measured during the running segment of a classic triathlon, with particular emphasis on the time course of these responses. Seven male triathletes underwent four successive laboratory trials: (1) 40 km of cycling followed by a 10-km triathlon run (TR), (2) a 10-km control run (CR) at the same speed as TR, (3) an incremental treadmill test, and (4) an incremental cycle test. The following ventilatory data were collected every minute using an automated breath-by-breath system: pulmonary ventilation ($\dot{V}_E$, $l \cdot min^{-1}$), oxygen uptake ($\dot{V}O_2$, $ml \cdot min^{-1} \cdot kg^{-1}$), carbon dioxide output ($ml \cdot min^{-1}$), respiratory equivalents for oxygen ($\dot{V}_E/\dot{V}O_2$) and carbon dioxide ($\dot{V}_E/\dot{V}CO_2$), respiratory exchange ratio (R) respiratory frequency (f, $breaths \cdot min^{-1}$), and tidal volume (ml). Heart rate (HR, $beats \cdot min^{-1}$) was monitored using a telemetric system. Biomechanical variables included stride length (SL) and stride frequency (SF) recorded on a video tape. The results showed that the following variables were significantly higher (analysis of variance, $P < 0.05$) for TR than for CR: $\dot{V}O_2$ [51.7 (3.4) vs 48.3 (3.9) $ml \cdot kg^{-1} \cdot min^{-1}$, respectively], $\dot{V}_E$ [100.4 (1.4) $l \cdot min^{-1}$ vs 84.4 (7.0) $l \cdot min^{-1}$], $\dot{V}_E/\dot{V}O_2$ [24.2 (2.6) vs 21.5 (2.7)] $\dot{V}_E/\dot{V}CO_2$ [25.2 (2.6) vs 22.4 (2.6)], f[55.8 (11.6) vs 49.0 (12.4) $breaths \cdot min^{-1}$] and HR [175 (7) vs 168 (9) $beats \cdot min^{-1}$]. Moreover, the time needed to reach steady-state was shorter for HR and $\dot{V}O_2$ (1 min and 2 min, respectively) and longer for $\dot{V}_E$ (7 min). In contrast, the biomechanical parameters, i.e. SL and SF, remained unchanged throughout TR versus CR. We conclude that the first minutes of the run segment after cycling in an experimental triathlon were specific in terms of $\dot{V}O_2$ and cardiorespiratory variables, and nonspecific in terms of biomechanical variables.

Key words Triathlon · Cardiorespiratory variables · Stride length · Stride frequency · Cycle-run transition

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Introduction

The physiological characteristics of the entire triathlon race and the separate segments have been well specified by numerous authors (Farber et al. 1991; Roalstad 1989; Schneider et al. 1990). Kreider et al. (1988a) showed that cycle exercise increases the oxygen cost of subsequent running. In a second study, these authors reported a decrease in metabolic efficiency during a simulated triathlon session (Kreider et al. 1988b). This was corroborated by Guezennec et al. (1996), who compared the run segment of a classic triathlon (1.5 km swimming, 40 km cycling, 10 km running) to a 10-km control run performed at the same speed and demonstrated, in an outdoor triathlon study with a portable telemetry system, an increase in the oxygen cost of running after the cycling segment. These results agree with physiological investigation that have demonstrated a slow rise in oxygen uptake ($\dot{V}O_2$) during constant-intensity, prolonged exercise (Bahr et al. 1991; Casaburi et al. 1987; Hagberg et al. 1978; Poole et al, 1991; Whipp and Wasserman 1972).

This increase in the oxygen cost of the third segment of a triathlon could be due to biomechanical and/or physiological causes. For example, Morgan et al. (1989) have identified a range of physiological and biomechanical variables that may influence running efficiency.

In particular, Hogberg (1952) reported that changes in the optimal stride induced a rise in the energetic cost of running. Kohrt et al. (1989a, b) reported physiological changes after the cycling segment of a triathlon, particularly dehydration, hyperthermia and energetic depletion, that could affect the performance of the subsequent running segment.

Today, triathlon training consists mainly of multiple swimming-cycling and cycling-running bouts because the results in triathlon competition seem to be related to the ability to link the separate events. Indeed, new rules established by the International Triathlon Union now allow drafting during the cycling segment, which has resulted in the formation of clusters of triathletes during this segment. Thus, the run has become the essential segment in terms of the final result, and particularly the first minutes of running just after cycling, referred to as the "cycle-run transition", which may affect the running efficiency of the remaining run. Otto et al. (1985) reported that the run time of a triathlon was significantly related to treadmill maximal oxygen uptake ($\dot{V}O_{2\,max}$), but Roalstad (1989) suggested that the relationship between $\dot{V}O_{2\,max}$ and performance may not be as strong as that often seen in single sports, and that preceding the run by cycling could affect the strength of the correlation between run $\dot{V}O_{2\,max}$ and triathlon run performance.

The aim of the present study was to assess the effects of the 40-km cycling segment of a classic triathlon on the biomechanical and cardiorespiratory variables of the subsequent run segment, compared with a control run, with particular emphasis on the time course of the responses in order to specify the characteristics of the cycle-run transition.

Methods

Subjects

Seven male competitive triathletes participated in this study. All were students at the School of Physical Education at the University of Montpellier, France, and members of the university athletic team which has been, for 4 consecutive years, French national champion in the triathlon. All had been competing in the triathlon for 5.0 (2.3) years and were in the competitive period at the time of the study. Anthropometric data and training regimens are reported in Table 1. All subjects were informed of the purpose of the study and gave written consent before participating.

Testing protocol

Each subject was tested in a four-phase protocol which took place over 4 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 own training schedule for the duration of the study, but were not allowed to compete in a triathlon during this period. On experiment days, the subjects were asked to abstain from training. Phase 1 consisted of 40 km of cycling followed by 10 km of a triathlon run (TR); phase 2 consisted of a 10-km control run (CR) at exactly the same speed evolutions (Fig. 1) as for TR; phase 3 consisted of an incremental treadmill test, and phase 4, of an incremental cycle test. In phase 1, the cycling was performed by triathletes using their own cycle set on a home trainer (Cycletrack, Tacx, Aardenburg, The Netherlands); speed and gear ratio were free, but estimated by the athletes to be close to their performance level in a classic triathlon, and above their cycling ventilatory threshold (Th_{vent}). Cardiorespiratory data were recorded during the first and last 10 km of the ride in order to allow the subjects to hydrate during the rest of the segment. Between the 10th and 30th kilometer, heart rate (HR, beats $\cdot$ min^{-1}) was monitered using a HR telemetric system (Polar Racer, Polar Electro Oy, Finland) in order to maintain the same intensity. Cycling distance was recorded using a bike odometer (Cateye Mity 2, Cateye, Osaka, Japan). At the end of the 40 km, subjects had 1 min (cycle-run change) to change their shoes and get on the treadmill (Gymroll 1800, HEF-Tecmachine, Andrézieux-Bouthéon, France). This time corresponded approximately to the cycle-run change time in an official triathlon. The athletes began TR at a speed calculated to be close to their performance level in a classic triathlon. This TR speed was reached in less than 1 min and was indicated by the treadmill digital odometer with 0.1 km $\cdot$ h^{-1} precision. Care was taken to stabilize the belt speed at the required speed using manual adjustment. The triathletes then adjusted their run speed by 0.5 km $\cdot$ h^{-1} $\cdot$ min^{-1} in order to optimize their running performance.

In phase 2, the triathletes warmed up by performing 1 km of running on the treadmill at 13 km $\cdot$ h^{-1}. They then recovered until their HR was below 100 beats $\cdot$ min^{-1}. CR was performed at exactly the same speed evolutions as for TR (km $\cdot$ h^{-1}). Phase 3 and phase 4 were used to measure $\dot{V}O_{2\,max}$ in the triathletes on a treadmill and a cycle ergometer in order to assess cycling, TR and CR intensities. The incremental treadmill test began at 5 km $\cdot$ h^{-1} for 1 min at 0% slope. The speed was then increased by 1 km $\cdot$ h^{-1} every minute up to 18 km $\cdot$ h^{-1}. The slope was then increased by 1% every minute up to exhaustion. The incremental cycle test was

Table 1 General physical characteristics, training regimen and results of the International Triathlon La Grande-Motte for seven male triathletes. Training distances were averaged weekly during the study period

Subject *n*	Age (years)	Height (cm)	Body mass (kg)	Mean training distances (km $\cdot$ week^{-1})			La Grande-Motte Triathlon	
				Swim	Bike	Run	Time (h:min)	Place
1	26	187	70	17	350	60	1:45	14
2	20	184	72	18	400	60	1:48	29
3	21	175	62	15	400	55	1:54	50
4	21	184	77	15	100	30	1:57	79
5	20	180	65	16	250	40	2:00	92
6	27	176	67	10	200	30	2:04	173
7	22	179	72	12	150	35	2:08	233
Mean	20.8	180.4	69.7	14.7	264.3	44.3	1:56	–
SD	2.9	3.0	4.5	2.8	121.5	13.7	0:08	–

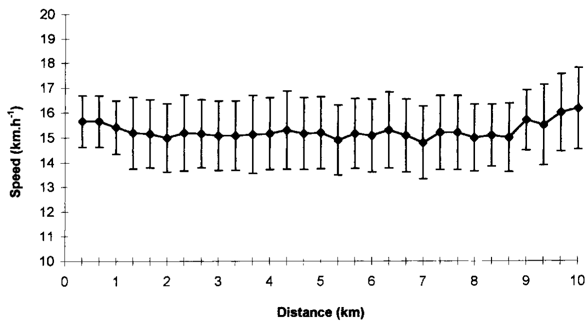


Fig. 1 The mean running speed evolution (km · h^{-1}) during the simulated 10-km triathlon run (*TR*). The running speed evolution during the 10-km control run (*CR*) was the same. The first 3 min were taken into account for each kilometer

performed on an electromechanical cycle ergometer. After a 3-min warm-up at 30 W · min^{-1} the power was then increased by 30 W every minute up to exhaustion.

Gas exchange measurement

The following cardiorespiratory data were collected every minute using a mass spectrometer breath-by-breath automated system (MGA-1100, Marquette, N.Y., USA): pulmonary ventilation ($\dot{V}_E$, l · min^{-1}), $\dot{V}O_2$ (ml · min^{-1} · kg^{-1}), carbon dioxide output ($\dot{V}CO_2$, ml · min^{-1}), respiratory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$) and for carbon dioxide ($\dot{V}_E/\dot{V}CO_2$), respiratory frequency (*f*, breaths · min^{-1}), and tidal volume (V_t ml). HR was measured using a telemetric system. To ensure that $\dot{V}O_{2max}$ was attained, at least three of the four following criteria had to be met: (1) an increase in $\dot{V}O_2$ lower than 100 ml with the last increase in work rate ("levelling off" criterion), (2) attainment of age-predicted maximal HR [210 − (0.65 × age) ± 10%; Spiro 1977], (3) respiratory exchange ratio (R) > 1.10, and (4) an inability to maintain the required running speed on the treadmill or the pedalling frequency (≥50 rpm) on the cycle ergometer despite maximal effort and verbal encouragement. The Th_{vent} was determined automatically using the V-slope method of Beaver et al. (1986). This method involves the analysis of $\dot{V}CO_2$ as a function of $\dot{V}O_2$ and assumes that Th_{vent} corresponds to the break point in the $\dot{V}CO_2$-$\dot{V}O_2$ relationship.

Biomechanical measurement

During phase 1 and 2, subjects were filmed by two cameras (Panasonic MSI SVHS 625, Japan) placed perpendicular to the treadmill. The first camera filmed the subject from the waist to the feet; the second camera was focused on the feet. Frames were transmitted to a monitor and recorded on a video tape. A video timer with a 1/100-s timer (VTG 33 J, FOR.A, Japan) was added to the video tape. The stride length (SL) and stride frequency (SF) were recorded instantaneously. According to Belli et al. (1995), SF should be calculated with a chronometer from the first 40 strides during the last 30 s of every minute to obtain accuracy in terms of mean values and variability of the mechanical parameters. SL was calculated simultaneously using the treadmill odometer.

Statistical analysis

The comparisons of cardiorespiratory and biomechanical data of TR and CR were made using a two-way analysis of variance (ANOVA) with repeated measures for $\dot{V}O_2$, $\dot{V}_E$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, R, V_t, f, HR, SL and SF. The comparisons of cardiorespiratory and biomechanical data of cycling and each minute of TR and CR were conducted using Student's t-test. A value of $P < 0.05$ was accepted as significant. All values are expressed as the mean (SD).

Results

Incremental tests

The $\dot{V}O_{2max}$ and Th_{vent} observed for the cycling and running incremental tests (Table 2) are in agreement with those reported by numerous authors (e.g. Roalstad 1989): 56.2–66.7 ml · kg^{-1} · min^{-1} for $\dot{V}O_{2max}$ cycle values and 52.4–68.8 ml · kg^{-1} · min^{-1} for $\dot{V}O_{2max}$ run values; 66.8% $\dot{V}O_{2max}$ and 71.9% $\dot{V}O_{2max}$ for Th_{vent} cycle and run values, respectively (Schneider et al. 1990).

Table 2 Maximal oxygen uptake ($\dot{V}O_{2max}$), ventilatory threshold (Th_{vent}) and heart rate (*HR*) values assessed throughout the incremental cycle test (cycle ergometer) and the incremental treadmill test (treadmill). No significant differences were observed

Tests	$\dot{V}O_2$			HR		
	max	Th_{vent}		max	Th_{vent}	
	ml · kg^{-1} · min^{-1}	ml · kg^{-1} · min^{-1}	% $\dot{V}O_{2max}$	beats · min^{-1}	beats · min^{-1}	% HR_{max}
Cycle Ergometer	65.4 4.2	42.5 6.5	65.0 9.9	181 14	148 12	81.8 6.6
Treadmill	62.1 6.3	46.4 6.3	74.7 10.1	190 13	155 13	81.6 6.7

Simulated triathlon intensity

The triathletes performed the 40-km cycling segment in (h:min:s) 1:02:41 (0:2:41) [mean speed, 38.28 (1.71) $km \cdot h^{-1}$] and TR and CR in 0:39:37 (0:3:40) [mean, 15.28 (1.40) $km \cdot h^{-1}$]. Since all of the triathletes ran every kilometer in more than 3 min, only the first 3 min of each kilometer was taken into account for the calculation of individual kilometer speed. The mean $\dot{V}O_2$ collected during the cycle, TR and CR segments corresponded to 73.5% of the cycle $\dot{V}O_{2max}$ and 83.2 and 77.6% of the treadmill $\dot{V}O_{2max}$, respectively. These mean $\dot{V}O_2$ values also corresponded to 113.4% of the Th_{vent} of the cycle ergometer test, and to 111.4% and 104.1% of the Th_{vent} of the treadmill running, respectively (Table 3).

Cardiorespiratory variables

The complete triathlon run versus the last 10 km of cycling showed that f and HR were significantly increased in TR whereas V_t was significantly decreased. Other cardiorespiratory data, $\dot{V}O_2$, $\dot{V}_E$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$ and R, were similar in TR and cycling.

A comparison between the triathlon run versus control run showed that TR induced a significant increase in mean $\dot{V}O_2$ and cardioventilatory data compared with CR, particularly for the $\dot{V}O_2$, $\dot{V}_E$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, f and HR time courses. R and V_t tended to be slightly higher in TR than in CR. Moreover, the cycle-run transition showed that, compared with the CR beginning, the TR transition exhibited specific changes. The $\dot{V}O_2$ TR mean value was reached at the 3rd min. In contrast, the $\dot{V}O_2$ CR mean value was reached at the 2nd min (Fig. 2). The $\dot{V}_E$ of TR was significantly lower than the $\dot{V}_E$ TR mean value for the first 2 min, and then was significantly higher than the $\dot{V}_E$ TR mean value until the 7th min. In contrast, the $\dot{V}_E$ of CR was significantly lower than the $\dot{V}_E$ CR mean value until the 7th min (Fig. 2). A significantly better efficiency in $\dot{V}_E/\dot{V}O_2$ was thus noted from the 7th min to the end of TR, with a significantly lower f and a significantly higher V_t at the 7th min of TR compared to TR mean. There were no changes in $\dot{V}_E/\dot{V}CO_2$ TR. In contrast, $\dot{V}_E/\dot{V}CO_2$ CR was lower than $\dot{V}_E/\dot{V}CO_2$ mean during the first 7 min and then was stabilized. R TR values were significantly higher than the mean R TR value until the 6th min. In contrast, R CR values reached the mean CR value at the 3rd min (Fig. 2). The cardiovascular transition showed that the HR TR mean value was reached after the 1st min of TR. In contrast, the HR CR mean value was reached at the 8th min of CR.

Biomechanical parameters

There were no changes for biomechanical variables, i.e. SL and SF, during the cycle-run transition or the entire TR. In contrast, a biomechanical adjustment in SF was noted during the first 7 min of CR (Fig. 3).

Discussion

This study shows that the 10-km run following 40 km of cycling had a higher oxygen cost than a 10-km run alone, whereas there were no differences in biomechanical variables, i.e. SL and SF. Moreover, the cycle-run transition showed specific oxygen and cardiorespiratory changes.

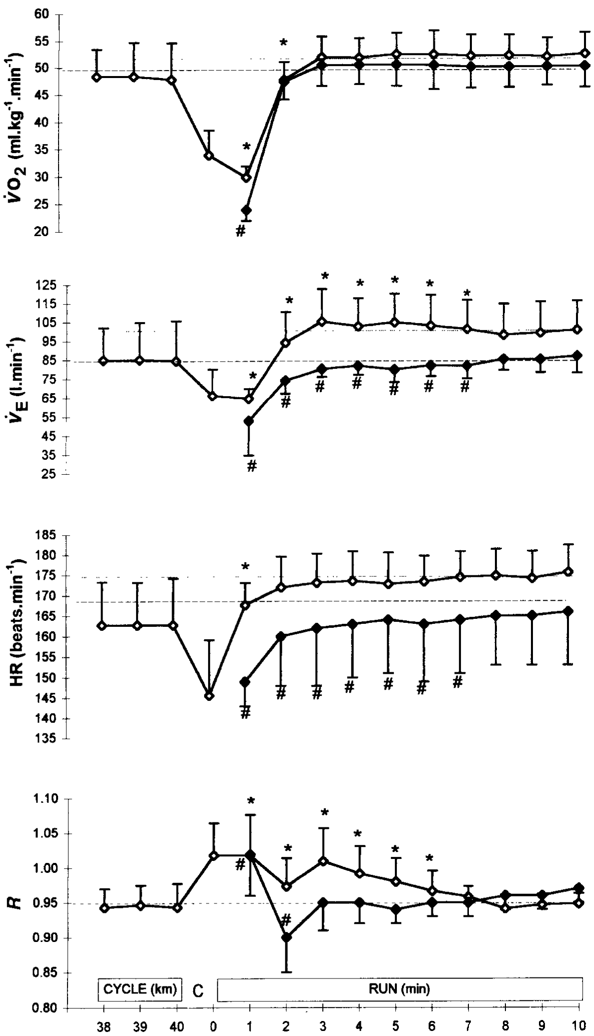
The percentages of $\dot{V}O_{2max}$ used during the cycling segment, TR and CR were 73.5%, 83.2% and 77.6%, respectively. These percentages were higher than those reported by Kreider et al. (1988a): 64, 78, and 73% $\dot{V}O_{2max}$ respectively, and by Guezennec et al. (1996): 78

Table 3 Cardiorespiratory values measured during the last 10 km of cycling, the cycle-run change, triathlon run (*TR*) and control run (*CR*). Values are means (SD). ($\dot{V}_E$ Pulmonary ventilation, $\dot{V}_E/\dot{V}O_2$ respiratory equivalent for oxygen, $\dot{V}_E/\dot{V}CO_2$ respiratory equivalent for carbon dioxide, R respiratory exchange ratio, f breathing frequency, V_t tidal volume)

Variables	Cycle last 10 km	Change 1 min	TR 10 km	CR 10 km
$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	48.2	33.9	51.7	48.3*
	(2.6)	(4.5)	(3.9)	(1.4)
$\dot{V}_E$ ($l \cdot min^{-1}$)	85.3	66.1	100.6	84.4*
	(19.4)	(14.1)	(14.7)	(7.0)
$\dot{V}_E/\dot{V}O_2$	21.7	24.7	24.1	21.5*
	(0.2)	(1.3)	(2.6)	(2.7)
$\dot{V}_E/\dot{V}CO_2$	22.8	24.1	25.2	22.4*
	(1.8)	(0.9)	(2.6)	(2.6)
R	0.94	1.01	0.96	0.95
	(0.02)	(0.04)	(0.01)	(0.02)
f ($breaths \cdot min^{-1}$)	43.3**	42.2	55.7	49.0*
	(2.9)	(5.7)	(11.5)	(12.3)
V_t (ml)	2007	1637	1873	1857
	(466)	(402)	(382)	(425)
HR ($beats \cdot min^{-1}$)	161**	145	177	167*
	(12)	(13)	(7)	(9)

* $P < 0.05$ TR versus CR
** $P < 0.05$ cycle versus TR

Fig. 2 Metabolic and cardiorespiratory variables during the last 3 km of cycling, the cycle-run change (*C*), the simulated triathlon run (◇) and the control run (◆). ($\dot{V}O_2$ Oxygen uptake, $\dot{V}_E$ pulmonary ventilation, *HR* heart rate, *R* respiratory exchange ratio). * significant difference for TR versus TR mean (- - - -). # significant difference for CR versus CR mean (—)



and 73% for a similar TR and CR. This indicates that the experimental triathlon in the present study was performed at a higher intensity, probably reflecting the high level of training and motivation of the triathletes. Although it is unusual for the $\dot{V}O_{2max}$ to be lower for treadmill running than for cycling, in a triathlete population the heavy training in three sports (swimming, cycling and running) tends to level the difference (Kohrt et al. 1989b; Roalstad 1989). Moreover, the greater quantity of training in cycling compared with running in this study (10 h per week in cycling versus 3 h per week in running) may also explain this unusual difference.

The results confirmed the metabolic increase of running after cycling versus control running alone reported in the literature (Guezennec et al. 1996; Kreider et al. 1988a; O'Toole 1989; O'Toole and Douglas 1989; O'Toole et al. 1989). Kreider et al. (1988a) reported that an experimental classic-distance triathlon run versus a control run elicited significant increases in $\dot{V}O_2$, $\dot{V}_E$, HR, arteriovenous oxygen difference and rectal temperature. Similarly, Guezennec et al. (1996) reported an increase of 3.5 ml · kg^{-1} · min^{-1} $\dot{V}O_2$, corresponding to 6–7% of CR $\dot{V}O_2$ during TR versus CR in an outdoor study using a $\dot{V}O_2$ portable telemetry system.

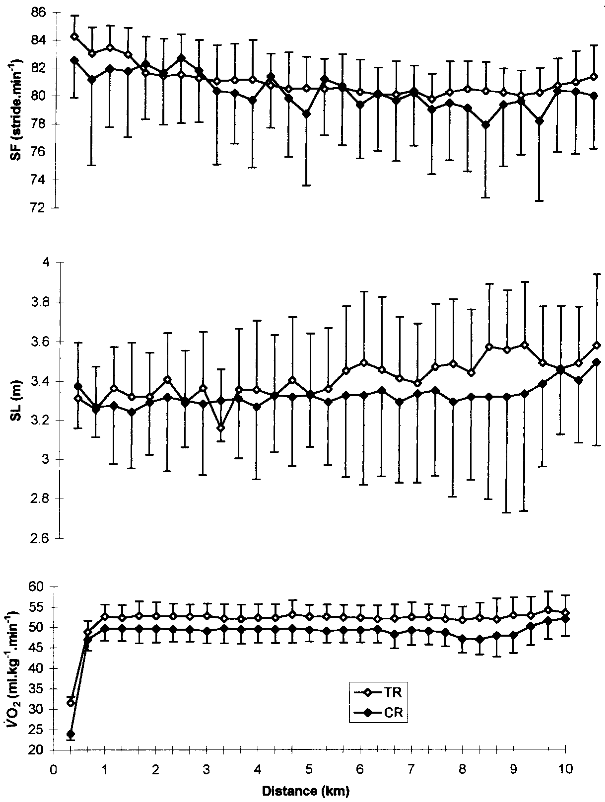


Fig 3 $\dot{V}O_2$, (ml · kg^{-1} · min^{-1}) and biomechanical parameters, i.e. stride length (*SL*) and stride frequency (*SF*), during TR and CR. $\dot{V}O_2$ was significantly higher during TR (*open diamonds*) versus CR (*filled diamonds*). No significant differences between the biomechanical variables were observed

Numerous physiological factors have been implicated in the increase in the oxygen cost of TR versus CR. The first may involve energetic substrates and be related to carbohydrate replacement by fat oxidation during prolonged exercise (Bulow 1988). Indeed, lipid mobilization has been reported to occur at the end of the triathlon (Van Rensburg et al. 1986) concomitant to muscle glycogen depletion (Armstrong et al. 1977). Unfortunately, the lack of *R* change during TR versus CR in the present study did not agree with this hypothesis and, in contrast, the high *R* values (>0.95) observed were consistent with the high carbohydrate dependence in endurance activities reported by O'Brien et al. (1993).

The second factor behind the $\dot{V}O_2$ increase during TR versus CR could be thermoregulation and dehydration, as suggested by Guezennec et al. (1986) and Douglas and Hiller (1989). The cycle segment could have induced dehydration and hyperthermia, resulting in an increase in HR and an upward drift in $\dot{V}_E$, which relates to a $\dot{V}O_2$ drift (Casaburi et al. 1987). In the present study, significant HR changes in TR versus CR were in accordance with this hypothesis.

The third factor could be lower ventilatory efficiency and/or exercise-induced hypoxaemia. Indeed, the subjects were running above their Th_{vent} but $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ values during TR [24.1 (2.6) and 25.2 (2.6), respectively] were higher than those reported for the treadmill $\dot{V}O_{2\,max}$ [24.0 (2.2) and 21.4 (1.6) respectively]. This indicates that the clearance of CO_2 released by the buffering of metabolic hydrogen ions, and respiratory compensation for the metabolic acidaemia, were not at their maximal level and thus cannot be considered as the only factors contributing to the ventilatory equivalent values. Therefore, some exercise-induced hypoxaemia could be suspected: $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ were significantly increased in TR versus CR, implying a greater increase in $\dot{V}_E$ than in $\dot{V}O_2$ and $\dot{V}CO_2$ in TR versus CR. Such an increase in both $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$, associated with an increase in *f*, has been reported to occur during respiratory muscle fatigue (Mador and Acevedo 1991) and during pulmonary interstitial oedema (Jay et al. 1986). Moreover, endurance athletes and especially triathletes have been found to present exercise-induced hypoxaemia, which could be at least partly due to an interstitial oedema, and which would lead to respiratory muscle fatigue by causing decreased pulmonary compliance (Caillaud et al. 1993; Prefaut et al. 1994).

The fourth factor could be the performance level of the triathletes. Quantitatively, the percentage rise in $\dot{V}O_2$ observed in the present study was 6–7% of $\dot{V}O_2$ CR, and was lower than that of 13% reported by O'Toole and Douglas (1989) in low-level triathletes. Laurenson et al. (1993) reported that the running of elite female triathletes was significantly more economical, showing a relatively lower $\dot{V}O_2$ than those of amateur female triathletes. Thus, high-level triathletes may be less tired at the end of the cycle segment than lower level triathletes, and the rise in $\dot{V}O_2$ TR would be more limited. Moreover, high-level triathletes may perform at their highest level over a longer time, and thus exhibit lower differences in TR versus CR speed, both runs being close to maximal aerobic run speed.

Biomechanical causes have been implicated in the increase in the energy cost of TR versus CR. Hogberg (1952) reported that changes in optimal stride induced a rise in the energetic cost. Cavanagh and Williams (1982) and Morgan et al. (1989) reported that variables such as SL could influence running economy. Davidson et al. (1986) suggested that the increasing oxygen cost in the run segment of a triathlon could be due to a variation in SL. The lack of change in the biomechanical parameters, i.e. SL and SF, reported in the present study in TR versus CR was also noted by Hausswirth et al. (1996), and these data are in disagreement with this hypothesis. However, Sleivert and Wenger (1993) reported that run velocity was the only predictor of overall triathlon time, and thus we may assume that biomechanical parameters other than SF and SL affect the running economy of TR, such as the centre of gravity position and its kinetics, knee elevation, trunk tilting (Thorstensson et al. 1984) and the modifications of the eccentric and concentric phases of the run (Frederick 1985). Kram and Taylor (1990) showed that the cost of running was determined by the cost of supporting the body mass and by the time course of force application, emphasizing the fact that it is the muscles which generate the force that determines the body's oxygen cost. An increased oxygen cost has been associated with muscle fatigue, which involves a modification in the muscular rigidity and the muscular compliance, both essential for motor efficiency (Sejersted and Vollestad 1992).

The $\dot{V}O_2$ at the beginning of TR was higher than at the beginning of CR, suggesting that $\dot{V}O_2$ had not fully returned to baseline in TR. Although the steady-state oxygen cost of CR was reached at the 2nd min, the cycle-run transition showed that the steady-state oxygen cost of TR was reached at the 3rd min, despite a higher $\dot{V}O_2$ at the end of the 1-min change period compared with the resting $\dot{V}O_2$ value observed at the beginning of CR. This "cycle-run transition" period, characterized by $\dot{V}O_2$ values during the first 2 min that were significantly lower than the $\dot{V}O_2$ mean, suggested an oxygen deficit, and that anaerobic metabolism delivered the required energy during these 2 min. This situation was emphasized by De Vito et al. (1995), who reported the ambiguity of triathletes at the beginning of TR, when the cycle segment has induced a decrease in their aerobic metabolism, whereas the energetic cost of TR is increased. This could prevent optimal performance because triathlon training results in general adaptations which enhance $\dot{V}O_{2max}$ at the expense of anaerobic capacity (Schneider et al. 1990).

The ventilatory time course indicated values during TR that were significantly higher than the mean $\dot{V}_E$ TR from the 3rd to the 7th min, whereas a similar $\dot{V}_E$ during CR showed significantly lower $\dot{V}_E$ values than the $\dot{V}_E$ CR mean value. The higher $\dot{V}_E$ noted during the cycle-run transition could be related to the prior cycle segment and the change period assimilated to a recovery period: the ventilatory response to the prior cycling had not fully recovered. This had been suggested by Kreider et al. (1988b), who demonstrated that triathlon performance elicited physiological adjustments that were not experienced when performing the events independently. The hyperventilation noted during the cycle-run transition was accompanied by concomitant changes in $\dot{V}_E$ efficiency, as assessed by $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$. This was different from the significantly lower $\dot{V}_E$ observed during the 1st min of CR. This decrease in ventilatory efficiency noted in TR could be related to respiratory changes reported during long-distance exercise, particularly exercise-induced hypoxaemia (Caillaud et al. 1993). Anselme et al. (1994) reported a hypoxaemia in triathletes, the cause of which could be pulmonary interstitial oedema, secondary to histamine release. Moreover, a decrease in ventilatory efficiency could also be related to respiratory muscle fatigue, as has been reported to occur in triathletes (Hill et al. 1991) and marathon runners (Chevrolet et al. 1993). The end of the ventilatory transition at the 7th min of TR was characterized by respiratory pattern changes, particularly a decrease in f and an increase in V_t, inducing an increase in ventilatory efficiency, as assessed by $\dot{V}_E/\dot{V}O_2$.

The HR during transition appeared to be shorter than over a similar period during CR. This could be due to the cycle segment which may induce higher blood catecholamine release (Hausswirth et al. 1996) and a decrease in stroke volume (Wells et al. 1987). This reinforces the role of HR in the cardiac output.

Finally, the cycle-run transition was characterized by no change in biomechanical parameters, i.e. SF and SL. This indicates that the cycle segment did not induce any perturbation in the biomechanical stride pattern. However, this cycle-run biomechanical transition was different from that observed during a similar CR period, which was characterized by a significant increase in SF from the 1st to the 7th min. This suggests that the cycle segment may induce a muscular fatigue which prevents the high SF noted at the beginning of CR.

In conclusion, the present study showed that the cycle-run transition in the triathlon is specific for metabolic and cardiorespiratory variables and is nonspecific for biomechanical parameters, i.e. SL and SF, when compared with the entire triathlon run or a control run. This reinforces the necessity for triathletes to practice multi-block training in order to simulate the physiological responses experienced by the swim-cycle and the cycle-run transitions.

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