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ORIGINAL ARTICLE

Pacing strategy during the initial phase of the run in triathlon: influence on overall performance

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Abstract The aim of the present study was to determine the best pacing strategy to adopt during the initial phase of a short distance triathlon run for highly trained triathletes. Ten highly trained male triathletes completed an incremental running test to determine maximal oxygen uptake, a 10-km control run at free pace and three individual time-trial triathlons (1.5-km swimming, 40-km cycling, 10-km running) in a randomised order. Swimming and cycling speeds were imposed as identical to the first triathlon performed and the first run kilometre was done alternatively 5% faster (Tri-Run$_{+5\%}$), 5% slower (Tri-Run$_{-5\%}$) and 10% slower (Tri-Run$_{-10\%}$) than the control run (C-Run). The subjects were instructed to finish the 9 remaining kilometres as quickly as possible at a free self-pace. Tri-Run$_{-5\%}$ resulted in a significantly faster overall 10-km performance than Tri-Run$_{+5\%}$ and Tri-Run$_{-10\%}$ ($p < 0.05$) but no significant difference was observed with C-Run ($p > 0.05$) (2,028 ± 78 s vs. 2,000 ± 72 s, 2,178 ± 121 s and 2,087 ± 88 s, for Tri-Run$_{-5\%}$, C-Run, Tri-Run$_{+5\%}$ and Tri-Run$_{-10\%}$, respectively). Tri-Run$_{+5\%}$ strategy elicited higher values for oxygen uptake, ventilation, heart rate and blood lactate at the end of the first kilometre than the three other conditions. After 5 and 9.5 km, these values were higher for Tri-Run$_{-5\%}$ ($p < 0.05$). The present results showed that the running speed achieved during the cycle-to-run transition is crucial for the improvement of the running phase as a whole. Triathletes would benefit to automate a pace 5% slower than their 10-km control running speed as both 5% faster and 10% slower running speeds over the first kilometre involved weaker overall performances.

Keywords Triathletes · Pace · Running speed · Long duration exercise · Fatigue · Central governor model · Previous experience

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Introduction

The Olympic distance triathlon (i.e. short distance triathlon) is a unique effort, which involves successively 1,500-m swimming, 40-km cycling and 10-km running. The ability to link the three triathlon disciplines in an optimal manner has been described as an important determinant of success (Bentley et al. 2002; Hausswirth and Brisswalter 2008). This observation is even more relevant for the cycle-to-run transition as all the recent studies conducted during ITU World Cup triathlon competitions (i.e. short distance triathlon) have reported high correlation between finish position and running performance for both genders (coefficients of correlation ranging from 0.71 to 0.99, $p < 0.01$) (Vleck et al. 2006, 2008; Le Meur et al. 2009). These coefficients of correlation were significantly lower considering overall ranking and both swimming performance (from 0.36 to 0.52, $p < 0.01$) and cycling performance (from "no significant correlation" to 0.74, $p < 0.05$) (Vleck et al. 2006, 2008; Le Meur et al. 2009).

In this context, several studies have focused on strategies for improving the performance during the triathlon run. These studies have identified drafting position (Hausswirth et al. 1999), variability in cycling power output production (Bernard et al. 2007), cycling cadence selection (Gotschall and Palmer 2002; Vercruyssen et al. 2005) and previous locomotion mode (Hausswirth et al. 1996, 1997) as the main determining factors of performance. On the other hand, less attention has been given to identify the best pacing strategy to adopt over the running leg. Only Kreider et al. (1988) showed that a progressive increase in running pace during the onset of the triathlon run allows the attainment of a ventilatory, cardiovascular, and neuromuscular steady-state. Recent studies have reported that triathletes tended to adopt a positive pacing during the run phase of ITU World Cup races, whereby after that a peak speed was reached, triathletes progressively slowed down (Vleck et al. 2006, 2008; Le Meur et al. 2009). During 2001 and 2002 Lausanne World Cup, most athletes ran faster over the first kilometre than most other run sections (Vleck et al. 2006, 2008), while residual effects of prior cycling are the highest and despite the recommendations of the current literature to adopt an even pacing strategy (i.e. constant pace) for physical events of such duration (for a review, see Abbiss and Laursen 2008). Similarly, Le Meur et al. (2009) showed that all of the 136 triathletes competing in the 2007 Beijing ITU WC event adopted a "positive pacing strategy" (whereby speed gradually declined, Abbiss and Laursen 2008) through the running phase. During this race, the first of the four laps was run 10.0% faster than the three remaining laps.

Accordingly, we hypothesised that a positive pacing during the running phase of a short distance triathlon is the best strategy to achieve the best overall performance for highly trained triathletes. The aim of the present investigation was to compare the effectiveness of three different pacing strategies during the initial phase of a 10-km triathlon run, while respecting normal triathlon conditions. As the transition from cycling to running represents the most critical and strategic phase affecting finish position, we investigated the effects of the pace adopted over the first run kilometre on the overall triathlon performance.

Materials and methods

Participants

Ten well-motivated male triathletes currently competing at a national level and selected on the basis of their performance time over the short distance triathlon (2h 2 min ± 7 min) volunteered to take part in this experiment. They had trained regularly and competed in triathlons for at least 4 years. Their characteristics are presented in Table 1. The triathletes were fully informed of the content of the experiment, and written consent was obtained before any testing, according to local ethical committee guidelines (Saint Germain en Laye, France). To familiarise the triathletes with the cycling and running circuits used in the experiment, a training camp was programmed 10 days before with a light training programme. During the entire experimental procedure, the subjects did not perform any exhausting exercise in the 48 h preceding each test.

Maximal running test

Prior to the experiment, each subject underwent a running test to determine maximal oxygen uptake ($\dot{V}O_{2\,max}$) and ventilatory thresholds (VT1, VT2) on a track where the increment of speed was fixed at 1 km h^{-1} each 3 min. Oxygen uptake ($\dot{V}O_2$) and expiratory flow ($\dot{V}_E$) were recorded breath by breath with a telemetric gas exchange measurement system (Cosmed K4b^2, Rome, Italy). Heart rate values (HR) were monitored every second using a Polar unit (RS800sd, Polar Electro, Kempele, Finland). Expired gases and HR values were subsequently averaged every 5 s. $\dot{V}O_{2\,max}$ was determined according to criteria described by Howley et al. (1995)—that is, a plateau in $\dot{V}O_2$ despite an increase in running speed, a respiratory exchange ratio value of 1.15, or a Heart rate (HR) over 90% of the predicted maximal HR. $\dot{V}O_{2\,max}$ was then determined as the highest value of $\dot{V}O_2$ achieved during a period of 30 s. The first and the second ventilatory thresholds (VT1 and VT2, respectively) were determined according to criteria previously described by Beaver et al. (1986). VT1 was determined as the first breakpoint where

Table 1 Characteristics of the subjects participating in the present study ($n = 10$)

Age (years)	24 ± 3
Height (cm)	178 ± 5
Weight (kg)	68.2 ± 6.7
Swimming training (km week^{-1})	12.5 ± 1.9
Cycling training (km week^{-1})	220 ± 42
Running training (km week^{-1})	65 ± 12
Running $\dot{V}O_{2\,max}$ (mL min^{-1} kg^{-1})	69.1 ± 7.1
Running $\dot{V}_{Emax}$ (L min^{-1})	184 ± 21
Running HR_{max} (beats min^{-1})	194 ± 7

Values are expressed as mean ± SD

$\dot{V}O_{2\,max}$ maximal oxygen uptake; $\dot{V}_{Emax}$ maximal minute ventilation; HR_{max} maximal heart rate we detected a systematic increase in $\dot{V}_E/\dot{V}O_2$ without a concomitant increase in $\dot{V}_E/\dot{V}CO_2$. VT2 was associated with the first breakpoint detected where $\dot{V}_E/\dot{V}CO_2$. started to increase concomitantly with $\dot{V}_E/\dot{V}CO_2$.

Control run

The first test was a 10-km run performed on a 340-m indoor running track (control run, C-Run). Pacing strategy was left free and the only instruction given to the triathletes was to run as fast as possible over the 10-km. No feedback was given about running speeds or split times. Subjects were informed of each kilometre completed. They had the possibility to drink 250 mL of water at the end of the 3rd, the 6th and the 9th kilometre.

The three triathlon sessions

All experiments (Fig. 1) were carried out in Paris, specifically at the French National Institute of Sport, Expertise and Performance (INSEP) from January to March. The study was conducted on indoor cycling and running tracks. Inside air temperatures ranged from 18 to 20°C. The three experimental triathlons were performed alone (i.e. time-trial triathlons) in a randomised order over the short distance (1.5-km swim, 40-km bike, 10-km run) with a 10-day recovery between them, where training load was minutely controlled. Heart rate at ventilatory thresholds (VT1, VT2) identified during the maximal running test were used to demarcate three intensity zones (Esteve-Lanao et al. 2007). These included zone 1, low-intensity exercise performed below VT1; zone 2, moderately high-intensity exercise in an intensity range between VT1 and VT2; and zone 3, high-intensity aerobic exercise performed above VT2. In the month prior to the first experimental trial, training durations and distributions of time spent in the three intensity zones were continuously monitored (15 ± 3 h week^{-1} and 79, 10, 12%, respectively). The mean training load was similar to previous data reported in the literature for trained triathletes (Hausswirth et al. 1997), high-level runners (Esteve-Lanao 2007), elite rowers (Fiskestrand and Seiler 2004) and cross-country skiers (Seiler and Kjerland 2006). Throughout the entire experiment, all subjects were coached by the same person. Training load was controlled to be similar in the duration between each test and similar to the participants usual training pattern. Triathletes were restricted to train in zone 1 during each couple of days following or preceding each test. To avoid injuries or overreaching, daily feedback was also obtained from triathletes and taken into account.

Swimming–cycling phase

The swim was staged in an indoor 50-m pool (24–25°C) wearing a singlet. The 40-km bike segment was conducted on a cycling track (166 m) next to the pool. The swim-cycle combination was performed in the three experiments at the same speed as the first triathlon, which was completed as fast as possible. The swimming velocity was controlled using a pacer placed in the swimming cap (Tempo Trainer, Finis®, Helsinki, Finland), which provided a ring signal each period of time needed for the completion of 12.5 m. During the first triathlon, they were asked to swim with an even paced strategy. During the first 3 km of the bike,

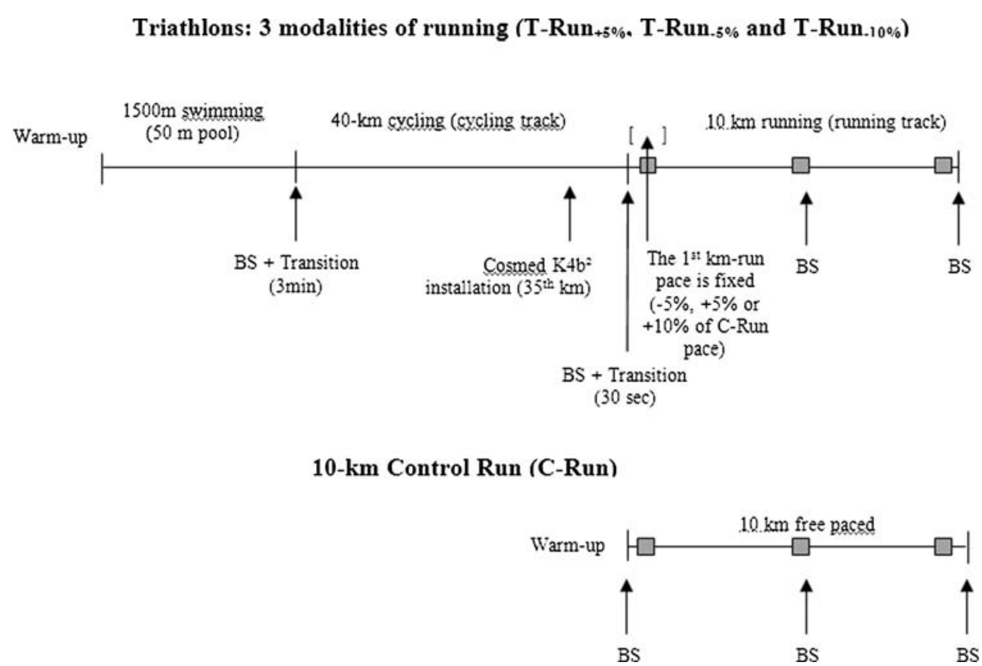

Fig. 1 Graphic representation of the three triathlon conditions and the control run. *BS* blood samples. *Dark portions* represent $\dot{V}O_2$ and $\dot{V}_E$ interval measurements. Tri-Run$_{+5\%}$, Tri-Run$_{-5\%}$, Tri-Run$_{-10\%}$ represent triathlon, whose first run kilometre was done 5% faster, 5% slower and 10% slower than the control run (C-Run). The 9 remaining kilometres were left free

triathletes had to reach the speed to be maintained during the last 37 km. A ring signal at each half-lap (83 m) indicated precisely the speed they had to keep. The speed of the last 37 km was the one reached from the second to the third kilometre, considering therefore that the two first kilometres was the distance necessary to reach a constant speed (Hausswirth et al. 2001). During the cycling sections, triathletes could drink ad libitum thanks to 750 mL water bottles disposed on their bikes. The transition time between swimming–cycling was slightly different from those obtained in competition (i.e. 3 min). It included 1 min for the change of clothes, 1 min for the cardiofrequency meter installation on the subject and 1 min for the run with the bike to reach the cycling track (200 m).

Running phase

The 10-km run was staged next to the cycling track, on the same indoor synthetic running track as the C-Run (340 m). During the first kilometre, subjects had to maintain alternatively a running speed 5% faster (Tri-Run$_{+5\%}$), 5% slower (Tri-Run$_{-5\%}$) and 10% slower (Tri-Run$_{-10\%}$) than the mean speed of the C-Run. The subjects were then instructed to finish the nine remaining kilometres as quickly as possible, as in a competitive event. Tri-Run$_{+5\%}$ condition was representative of the strategy adopted by highly trained triathletes in competition during the cycle-to-run transition (Le Meur et al. 2009). Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$ were closer to the mean velocity they used to maintain during short distance triathlon. A ring signal each 25 m indicated precisely the speed the subject had to keep over the first kilometre. Then, the only instruction given was to run as fast as possible until the finish line. They were given distance feedback each kilometre completed. During the three triathlon tests, athletes were encouraged to drink 250 mL after 3, 6 and 9 km.

Measurement of kinematic variables

Running speed was continuously recorded thanks to a s3 accelerometer (Polar RS800sd, Kempele, Finland) (Hausswirth et al. 2009). Three days before the first test, it was calibrated to integrate each runner's stride characteristics, as recommended by the manufacturer. Subjects had to follow a pace close to the speed they would adopt over the control run (i.e. 18 km h^{-1}) for 2 km. They received audio cues via a beeper; the cue rhythm determined the speed needed to cover 20 m.

Measurement of metabolic variables

After 35-km of cycling, the subjects were stopped to be equipped with the same portable gas analyser employed during the running pre-test. Thus, the cycle-to-run transition was reduced in time in order to reproduce competition conditions (i.e. 30 s) (Millet and Vleck 2000). The physiological data ($\dot{V}O_2$, $\dot{V}_E$) were averaged every 5 s from the breath-by-breath values. They were analysed at the beginning (0.5–1 km), in the middle (4.5–5 km) and at the end of each run (9–9.5 km).

Blood sampling

Blood samples were taken from ear lobes at the end of the cycling phase, after 5 km of running and at the end of the 10-km run for the analysis of blood lactate concentration ($[La^-]_b$) (Lactate Pro, Akray Inc, Kyoto, Japan).

Statistical analyses

All data were expressed as mean ± standard deviation. A two-way analysis of variance (pacing strategy × time period) for repeated measures was performed to analyse the effects of the time period and the pace adopted during the first run kilometre using running speed, HR, $\dot{V}O_2$, $\dot{V}_E$ and $[La^-]_b$ values as dependent variables. A Newmann-Keuls post hoc test was used to determine differences among all paces and periods during exercise. The level of significance was set at $p < 0.05$ for all statistical procedures.

Results

All subjects completed the protocol without problem and remarked that both C-Run and triathlon trials were perceptually similar to competition races.

Training load

No significant difference in training volume and training session distribution in zone 1, zone 2 and zone 3 were found between each 10-day period elapsing two tests ($p = 0.97$).

Performances

No significant difference was observed between the swimming–cycling phases of the three triathlon sessions ($p > 0.05$, Table 2). There was a systematic significant difference in time required to complete the first 1 km in relation to the starting strategy (200 ± 15, 190 ± 14, 210 ± 17 and 220 ± 18 s for C-Run, Tri-Run$_{+5\%}$, Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$, respectively, p ranging from 0.001 to 0.014). Tri-Run$_{-5\%}$ resulted in a significantly faster overall 10-km run performance than Tri-Run$_{+5\%}$ and Tri-Run$_{-10\%}$ ($p = 0.005$ and $p = 0.02$, with Tri-Run$_{+5\%}$ and Tri-Run$_{-10\%}$,

Table 2 Overall and isolated performances achieved during the three triathlons

Perf. conditions	Swimming time (s)	Cycling time (s)	Running time (s)	Overall time (s)
C-Run			$2{,}000 \pm 72^{\mu\mu,££}$	
Tri-Run$_{+5\%}$	$1{,}278 \pm 54$	$4{,}260 \pm 52$	$2{,}178 \pm 121^{**,\$\$,\mu\mu}$	$7{,}716 \pm 196^{\$\$,\mu\mu}$
Tri-Run$_{-5\%}$	$1{,}275 \pm 51$	$4{,}255 \pm 50$	$2{,}028 \pm 78^{£,£,\mu}$	$7{,}558 \pm 188^{££,\mu}$
Tri-Run$_{-10\%}$	$1{,}281 \pm 52$	$4{,}263 \pm 57$	$2{,}087 \pm 88^{\$,*,£}$	$7{,}631 \pm 191^{\$,£}$

Values are expressed as mean ± SD

Significantly different from C-Run group, * $p < 0.05$, ** $p < 0.01$

Significantly different from Tri-Run$_{+5\%}$, $^{£}$ $p < 0.05$, $^{££}$ $p < 0.01$

Significantly different from Tri-Run$_{-5\%}$, $^{\$}$ $p < 0.05$, $^{\$\$}$ $p < 0.01$

Significantly different from Tri-Run$_{-10\%}$, $^{\mu}$ $p < 0.05$, $^{\mu\mu}$ $p < 0.01$

respectively) but no significant difference with C-Run ($p = 0.58$) ($2{,}028 \pm 78$ s and 17.8 ± 0.4 km h^{-1} vs. $2{,}000 \pm 72$ s and 18.0 ± 0.6 km h^{-1}, $2{,}178 \pm 121$ s and 16.5 ± 0.9 km h^{-1}, $2{,}087 \pm 88$ s and 17.2 ± 0.6 km h^{-1}, for Tri-Run$_{-5\%}$, C-Run, Tri-Run$_{+5\%}$ and Tri-Run$_{-10\%}$, respectively, Table 2).

Physiological parameters

Table 3 indicates mean values for HR, $\dot{V}O_2$, $\dot{V}_E$ and blood lactate for the running bouts.

Time period effect $\dot{V}O_2$, $\dot{V}_E$ and HR at the middle and at the end of the run tended to be lower than their corresponding initial value during Tri-Run$_{+5\%}$ ($p = 0.081$ and $p = 0.085$ for $\dot{V}O_2$, $p = 0.071$ and $p = 0.080$ for $\dot{V}_E$, $p = 0.080$ and $p = 0.057$ for HR, when considering km-5 and km-10 with km-1, respectively). On the contrary, $\dot{V}_E$ and HR were significantly higher after 5 and 9.5-km than at the beginning of the run for C-Run, Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$ ($p = 0.041$ and $p = 0.008$ and $p = 0.011$ for $\dot{V}_E$, $p = 0.035$ and $p = 0.003$ and $p = 0.006$ for HR, when considering km-5 and km-10 with km-1, for C-Run, Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$, respectively). No significant difference was observed between 5-km $[La^-]_b$ and corresponding initial values excepted for Tri-Run$_{+5\%}$, whose $[La^-]_b$ value increased from 2.9 ± 0.2 to 4.9 ± 0.5 mmol L^{-1} during this period ($p = 0.035$). All final $[La^-]_b$ values for all the runs were significantly higher than their corresponding initial values ($p = 0.014$, $p = 0.021$, and $p = 0.029$, for C-Run, Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$, respectively).

Pacing strategy effect

The statistical analysis indicated a significant effect of pacing strategy on $\dot{V}O_2$, $\dot{V}_E$ and HR during the first kilometre of the running phase ($p < 0.05$). $\dot{V}O_2$, $\dot{V}_E$ and HR recorded during Tri-Run$_{+5\%}$ after km-1 were indeed significantly higher than C-Run, Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$ ($p < 0.05$, Table 3). On the contrary, $\dot{V}O_2$, $\dot{V}_E$, HR and $[La^-]_b$ during Tri-Run$_{-5\%}$ were higher than during the three other conditions after 5 and 9.5-km ($p < 0.05$), except $[La^-]_b$ at km-5 ($p = 0.12$). Tri-Run$_{+5\%}$ demonstrated greater $[La^-]_b$ at km-5 than C-Run and the two other triathlon runs ($p = 0.031$, $p = 0.033$, and $p = 0.038$, when considering C-Run, Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$ with Tri-Run$_{+5\%}$, respectively).

Discussion

The main finding of this study was that the best initial pacing strategy during the running leg of a triathlon is to perform the first kilometre 5% slower than the average pace of a 10-km control run. A 20 s-variation in running time over the first kilometre led to a significant difference of 150 ± 21 s on the 10-km triathlon run performance. This result is even more relevant considering that the differential time at the finish line between the top 10 triathletes during World Cup triathlons is usually shorter than 1 min (Millet and Vleck 2000; Vleck et al. 2006, 2008; Le Meur et al. 2009). To our knowledge, this study is the first to highlight performance improvements by forcing highly trained athletes to change their usual pattern of energy expenditure.

In the present study, triathletes significantly increased their 10-km C-Run time by 1.4, 4.4 and 8.9% during Tri-Run$_{-5\%}$, Tri-Run$_{-10\%}$ and Tri-Run$_{+5\%}$, respectively ($p < 0.05$, Fig. 2). The adoption of a fast pace during the first run kilometre induced a significant subsequent slowdown until the third kilometre (the 9 remaining kilometres were performed 2.7 ± 0.4 km h^{-1} slower than the first one during Tri-Run$_{+5\%}$, $p < 0.01$; Fig. 2). Conversely, triathletes succeeded in increasing their speed by 1.0 ± 0.3 km h^{-1} over the same section during Tri-Run$_{-5\%}$ (Fig. 2).

The main explanation to elucidate the weaker performance observed during the Tri-Run$_{+5\%}$ time-trial is that the pace was centrally down-regulated in a feed-forward manner to avert premature fatigue during exercise, as already proposed by Ulmer (1996). Tucker (2009) has recently proposed that alterations in pacing strategy occur

Table 3 Group mean (±SD) values for oxygen uptake, expiratory flow, heart rate and blood lactate obtained during the run sessions

Param. Runs	Oxygen uptake ($\dot{V}O_2$) mL min^{-1} kg^{-1})			Expiratory flow ($\dot{V}_E$) (L min^{-1})			Heart rate (HR) (beats min^{-1})			Blood lactate ($[La^-]_b$) (mmol L^{-1})		
Distance (km)	0.5–1	4.5–5	9–9.5	0.5–1	4.5–5	9–9.5	0.5–1	4.5–5	9–9.5	0	5	10
C-Run	$61.5 \pm 5.1^{\$}$	$60.7 \pm 5.8^{\$£}$	$64.4 \pm 5.7^{£\$\$}$	$173.2 \pm 12.3^{\$}$	$179.8 \pm 14.3^{\$\$£}$	$182.1 \pm 9.5^{\$\$£}$	$176.2 \pm 17.3^{£}$	$186.2 \pm 17.9^{\$}$	$189.3 \pm 18\ 0.2^{\$\$}$	$0.8 \pm 0.3^{\$\$£}$	$3.2 \pm 0.4^{\$}$	$3.4 \pm 0.3^{£}$
Tri-Run$_{+5\%}$	$66.1 \pm 7.0^{*£}$	$54.9 \pm 6.8^{*££}$	$55.1 \pm 6.7^{**££}$	$182.1 \pm 9.2^{*}$	$160.5 \pm 12.3^{**££}$	$162.1 \pm 13.4^{**£}$	$186.0 \pm 16.5^{*££}$	$176.1 \pm 14.8^{£*}$	$171.6 \pm 12.8^{**££}$	$2.9 \pm 0.2^{*}$	$4.9 \pm 0.5^{*£}$	$4.1 \pm 0.3^{£}$
Tri-Run$_{-5\%}$	$60.9 \pm 5.9^{\$}$	$65.3 \pm 5.8^{*\$\$}$	$68.1 \pm 6.8^{*\$\$}$	167.8 ± 8.2	$187.9 \pm 11.2^{*\$\$}$	$191.5 \pm 10\ 0.8^{*\$}$	$168.0 \pm 11.2^{*\$\$}$	$190.1 \pm 14.2^{\$}$	$192.8 \pm 12.8^{\$\$}$	$3.2 \pm 0.3^{*}$	$3.8 \pm 0.2^{\$}$	$5.4 \pm 0.4^{*\$}$
Tri-Run$_{-10\%}$	$55.1 \pm 4.9^{*\$\$£}$	$57.9 \pm 4.4^{\$££}$	$60.6 \pm 5.7^{*£\$}$	$158.5 \pm 10.8^{*\$£}$	$170.4 \pm 11.2^{*££\$}$	$164.2 \pm 12.1^{*££}$	$159.0 \pm 11.3^{**£\$\$}$	$181.1 \pm 17.8^{£}$	$180.1 \pm 17.2^{*£\$}$	$3.1 \pm 0.2^{*}$	$3.6 \pm 0.4^{\$}$	$4.0 \pm 0.4^{£}$

All $\dot{V}O_2$, $\dot{V}_E$ and HR values for both Tri-Run$_{-5\%}$ and Tri-Run$_{+5\%}$ were significantly different from the corresponding initial value, $p < 0.05$

All $\dot{V}_E$ and HR values for both C-Run and Tri-Run$_{-10\%}$ were significantly different from the corresponding initial value, $p < 0.05$

All final $[La^-]_b$ values for all Runs were significantly different from the corresponding initial value, $p < 0.05$

The 5-km $[La^-]_b$ values for Tri-Run$_{+5\%}$ were significantly different from the corresponding initial value, $p < 0.05$

Significantly different from C-Run group, * $p < 0.05$, ** $p < 0.01$

Significantly different from Tri-Run$_{+5\%}$ group, $^{\$}$ $p < 0.05$, $^{\$\$}$ $p < 0.01$

Significantly different from Tri-Run$_{-5\%}$ group, $^{£}$ $p < 0.05$, $^{££}$ $p < 0.01$

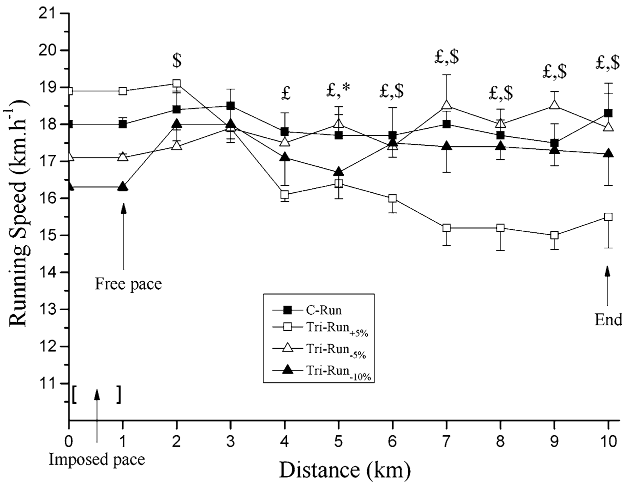

Fig. 2 Group mean (±SD) values for average running speeds (km h^{-1}) recorded every kilometer during the 10-km run for the Triathlon Runs where the first km was done alternatively 5% faster (Tri-Run$_{+5\%}$), 5% slower (Tri-Run$_{-5\%}$) and 10% slower (Tri-Run$_{-10\%}$) than the Control Run (C-Run): the 9 remaining kilometers were then free in all situations. All values for the Tri-Run$_{+5\%}$ were significantly different from the corresponding imposed initial pace (excepted for km-2 value), $p < 0.01$. All values for the Tri-Run$_{-10\%}$ were significantly different from the corresponding imposed initial pace (excepted for km-5 value), $p < 0.01$. [$]Significantly different within both Tri-Run$_{+5\%}$ and Tri-Run$_{-10\%}$, and within Tri-Run$_{+5\%}$ and Tri-Run$_{-5\%}$, $p < 0.05$ *Significantly different within both Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$, and within Tri-Run$_{-5\%}$ and Tri-Run$_{+5\%}$, $p < 0.05$. [£]Significantly different within Tri-Run$_{+5\%}$ and C-Run, $p < 0.05$

to prevent harmful or catastrophic changes from occurring before the end of exercise, while still optimising performance. Two major limiting physiological changes may be identified here; of metabolic and ventilatory origins respectively.

The present results revealed a significantly higher metabolic demand during the first kilometre of Tri-Run$_{+5\%}$ than during Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$ (−8.9 and −16.7% concerning $\dot{V}O_2$; −9.7 and −14.5% concerning $\dot{V}_E$, for Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$, respectively; $p < 0.05$, Table 3). After 5-km, we still observed a greater anaerobic contribution for Tri-Run$_{+5\%}$ than the two other strategies in spite of a significantly lower speed (4.9 ± 0.5 mmol L^{-1} and 16.4 ± 0.4 km h^{-1}, 3.8 ± 0.2 mmol L^{-1} and 18.0 ± 0.3 km h^{-1}, 3.6 ± 0.4 mmol L^{-1} and 16.7 ± 0.4 km h^{-1} for Tri-Run$_{+5\%}$, Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$, respectively; $p < 0.05$; Table 3). These results are in accordance with previous studies about pacing strategies in swimming (Thompson et al. 2003), cycling (Foster et al. 1993; Hettinga et al. 2006) and running (Billat et al. 2001), which demonstrated that a fast start induces a higher supply of anaerobic pathways to achieve a fixed distance. Moreover, Kreider et al. (1988) explained that the cycle-to-run transition causes a redistribution of blood flow between the different muscular groups involved during running. The delay in the shunting of blood to the upper extremities may then increase the rate of glycolysis in both trunk and arms' muscles. Tri-Run$_{+5\%}$ may then have induced higher metabolic disturbances through the overall run than Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$.

Another explanation was that a "negative pacing strategy" (i.e. whereby speed gradually would have increased) would have generated premature respiratory disturbances during the cycle-run transition. At the end of the first kilometre of Tri-Run$_{+5\%}$, triathletes reached 93.9 ± 6.1% of $\dot{V}_{Emax}$ determined from the laboratory incremental test. These values were significantly higher for Tri-Run$_{+5\%}$ than Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$ (86.5 ± 7.8% of $\dot{V}_{Emax}$ and 81.7 ± 6.9% of $\dot{V}_{Emax}$, for Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$, respectively; $p < 0.05$). Hill et al. (1991) demonstrated that the crouched position adopted by triathletes during cycling increases abdominal impedance and diaphragmatic work. Moreover, Boussana et al. (2001) reported that a moderate intensity cycle-to-run combination, not performed to exhaustion induced a decrease in respiratory muscle performance. Another study showed that the respiratory muscle fatigue induced by prior cycling was maintained and not reversed by the subsequent run (Galy et al. 2003). As triathletes reached here higher running intensity than during these studies (87% $\dot{V}O_{2\,max}$ vs. 75% $\dot{V}O_{2\,max}$), Tri-Run$_{+5\%}$ may have led to greater respiratory disturbances than Tri-Run$_{-5\%}$ and Tri-Run$_{-10\%}$.

Nevertheless, two major observations led us to hypothesise that the weaker performances observed during Tri-Run$_{+5\%}$ were mainly due to a reduction of the cognitive drive and not to a peripheral fatigue. First, triathletes succeeded to perform an "end-spurt" in the last kilometre, whereas they showed the typical symptoms of fatigue as indicated by the fall of running speed until the third kilometre (Fig. 2). Tucker (2009) has proposed that the occurrence of an end-spurt indicated that the distribution of pace selected during self-paced exercise is centrally regulated in accordance to an "anticipatory—feedback RPE model". This final increase in running speed during Tri-Run$_{+5\%}$ supported the notion that the pacing strategy selected was continuously altered throughout the event, possibly in response to changing afferent signals. It suggested that exercise demands were somewhat uncertain at commencement of the trial and gradually resolved as the endpoint approached. As a result, running pace was subconsciously attenuated until the last kilometre was reached. As the role of the regulatory processes was to ensure that severe derangements to homeostasis did not occur, this uncertainty may have resulted in the maintenance of a motor unit and metabolic reserve throughout Tri-Run$_{+5\%}$. From this perspective, the weaker performance achieved during Tri-Run$_{+5\%}$ would have been primarily due to a decrease in motor unit recruitment and not to an effective drastic failure of the ventilatory function or of the homeostasis in the exercising limbs. Moreover, peripheral fatigue results in a progressive decline in force production (Gandevia 2001). In the present experiment, we did not observe such a progressive fall in running speed but a sudden slowdown after km 2. Speed decreased by 1.5 km h^{-1} per kilometre between kilometre 2–4 and only by 0.2 km h^{-1} per kilometre during the five subsequent ones (Fig. 2). Thus, we speculated that the adoption of a fast running start may have generated a greater rate of received exertion (RPE) than the one the central controller considered optimal. We hypothesised that triathletes might have been suddenly restrained to slowdown until their RPE returned to a "tolerable" level.

Another interesting finding of our study was that the differential time between Tri-Run$_{-10\%}$ and Tri-Run$_{-5\%}$ reached 59 ± 11 s at the end of the race, even if the differential time was reached at 10 s at the end of the first kilometre. $\dot{V}O_2$, $\dot{V}_E$ and $[La^-]_b$ were significantly lower after 5 and 9.5 km for Tri-Run$_{-10\%}$ than Tri-Run$_{-5\%}$, suggesting that triathletes did not succeed in reaching the maximal workrate they might have been able to sustain. The reason of this finding remains unclear. Several field-based researches reported that triathletes adopted a high initial pace during the cycle-to-run transition during both competitions (Vleck et al. 2006, 2008; Le Meur et al. 2009) and multi-transition training sessions (Millet and Vleck 2000). For instance, Le Meur et al. (2009) showed that all of the 136 triathletes competing in the 2007 Beijing ITU WC event adopted a "positive pacing strategy" (whereby speed gradually declines, Abbiss and Laursen 2008) through the running phase. During this race, the first of the four laps was run 10.0% faster than the three remaining laps. Then, we can consider that Tri-Run$_{+5\%}$ represented the usual strategy experienced by triathletes and that Tri-Run$_{-10\%}$ was more distant than Tri-Run$_{-5\%}$ from triathletes' usual starting strategy. Over the first kilometre of Tri-Run$_{-5\%}$ triathletes were forced to start 20 s slower than they used to (i.e. Tri-Run$_{+5\%}$), whereas this differential starting time reached 30 s during Tri-Run$_{-10\%}$ (Fig. 2). This finding could be linked with several studies, which have demonstrated that the pacing strategy is influenced by prior experience (Ansley et al. 2004; Mauger et al. 2009; Micklewright et al. 2009; Foster et al. 2009). A recent research conducted by Foster et al. (2009) demonstrated that the pattern of energy expenditure during time trial exercise appears to follow a predetermined template associated with prior experience, which is modified by a variety of sensory feedbacks mechanisms. From this perspective, Tri-Run$_{-10\%}$ may have been more disturbing for triathletes than Tri-Run$_{-5\%}$ by providing more atypical internal feedbacks than those they usually perceived during the cycle-to-run transition (see physiological responses in Table 3). The present results suggested that the higher the sensory feedbacks were modified comparing to prior experience, the more triathletes had difficulties to adjust their pace. We speculated that triathletes would have taken benefits particularly from further experimentations of Tri-Run$_{-10\%}$ strategy to improve their ability to adjust quickly and to maintain an optimal pace after a slow first kilometre. Indeed Mauger et al. (2009) have demonstrated recently that cyclists completed a time-trial closed to their personal best—without any external feedbacks—only if previous experience (i.e. at least 4 time trials) has been gained to develop the appropriate optimal strategy. Similarly, Foster et al. (2009) showed that the "anticipatory-feedback RPE model" is not a non-constant feature and may require some time to fully develop. Further studies are required to confirm this hypothesis.

In conclusion, this study demonstrated that elite triathletes should slightly reduce their freely chosen pace over the first run kilometre of short distance triathlons. The present results showed that pacing during the cycle-to-run transition is crucial for the development of the running phase as a whole. In this context, the best running strategy following cycling is to perform the first kilometre 5% slower than the average speed of a 10-km control run. Highly trained triathletes would benefit to automate this particular pace during back to back cycle-run training as both slower and higher initial running speed led to weaker performance. Considering the high correlation systematically reported between finish position and running performance during ITU World Cup races for both sexes (Vleck et al. 2006, 2008; Le Meur et al. 2009), pacing might be the main factor in improving the running performance achieved in competition by world-class triathletes.

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