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**TITLE: PACING STRATEGY DURING THE INITIAL PHASE OF THE RUN IN  
TRIATHLON: INFLUENCE ON OVERALL PERFORMANCE**

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1 **ABSTRACT**

2 **Objective:** The aim of the present study was to determine the best pacing strategy to adopt  
3 during the initial phase of a short distance triathlon run for highly-trained triathletes.

4 **Methods:** Ten highly-trained male triathletes completed an incremental running test to  
5 determine maximal oxygen uptake, a 10-km control run at free pace and three individual time-  
6 trial triathlons (1.5-km swimming, 40-km cycling, 10-km running) in a randomised order.  
7 Swimming and cycling speeds were imposed as identical to the first triathlon performed and  
8 the first run kilometre was done alternatively 5% faster (Tri-Run<sub>+5%</sub>), 5% slower (Tri-Run<sub>-5%</sub>)  
9 and 10% slower (Tri-Run<sub>-10%</sub>) than the control run (C-Run). The subjects were instructed to  
10 finish the 9 remaining kilometres as quickly as possible at a free self-pace.

11 **Results:** Tri-Run<sub>-5%</sub> resulted in a significantly faster overall 10-km performance than Tri-  
12 Run<sub>+5%</sub> and Tri-Run<sub>-10%</sub> ( $p<0.05$ ) but no significant difference was observed with C-Run  
13 ( $p>0.05$ ) (2028±78s vs. 2000±72s, 2178±121s and 2087±88s, for Tri-Run<sub>-5%</sub>, C-Run, Tri-  
14 Run<sub>+5%</sub> and Tri-Run<sub>-10%</sub>, respectively). Tri-Run<sub>+5%</sub> strategy elicited higher values for oxygen  
15 uptake, ventilation, heart rate and blood lactate at the end of the first kilometre than the three  
16 other conditions. After 5 and 9.5 kilometres, these values were higher for Tri-Run<sub>-5%</sub> ( $p<0.05$ ).

17 **Conclusions:** The present results showed that the running speed achieved during the cycle-to-  
18 run transition is crucial for the improvement of the running phase as a whole. Triathletes  
19 would benefit to automate a pace 5% slower than their 10-km control running speed as both  
20 5% faster and 10% slower running speeds over the first kilometre involved weaker overall  
21 performances.

22 **Keywords:** Triathletes, Pace, Running speed, Long duration exercise, Fatigue, Central  
23 governor model, Previous experience

24

# 1 INTRODUCTION

2

3 The Olympic distance triathlon (*i.e.* short distance triathlon) is a unique effort, which involves  
4 successively 1500 m swimming, 40-km cycling and 10-km running. The ability to link the  
5 three triathlon disciplines in an optimal manner has been described as an important  
6 determinant of success (Bentley et al. 2002, Hauswirth and Brisswalter 2008). This  
7 observation is even more relevant for the cycle-to-run transition as all the recent studies  
8 conducted during ITU World Cup triathlon competitions (*i.e.* short distance triathlon) have  
9 reported high correlation between finish position and running performance for both genders  
10 (coefficients of correlation ranging from 0.71 to 0.99,  $p < 0.01$ ) (Vleck et al. 2006, Vleck et  
11 al. 2008; Le Meur et al. 2009). These coefficients of correlation were significantly lower  
12 considering overall ranking and both swimming performance (from 0.36 to 0.52,  $p < 0.01$ )  
13 and cycling performance (from “no significant correlation” to 0.74,  $p < 0.05$ ) (Vleck et al.  
14 2006, Vleck et al. 2008, Le Meur et al. 2009).

15

16 In this context, several studies have focused on strategies for improving the performance  
17 during the triathlon run. These studies have identified drafting position (Hauswirth et al.  
18 1999), variability in cycling power output production (Bernard et al. 2007), cycling cadence  
19 selection (Gotschall et al. 2002, Vercruyssen et al. 2005) and previous locomotion mode  
20 (Hauswirth et al. 1996, Hauswirth et al. 1997) as the main determining factors of  
21 performance. On the other hand, less attention has been given to identify the best pacing  
22 strategy to adopt over the running leg. Only Kreider et al. (1988) showed that a progressive  
23 increase in running pace during the onset of the triathlon run allows the attainment of a

1 ventilatory, cardiovascular, and neuromuscular steady-state. Recent studies have reported that  
2 triathletes tend to adopt a positive pacing during the run phase of ITU World Cup races,  
3 whereby after that a peak speed was reached, triathletes progressively slowed down (Vleck et  
4 al. 2006, Vleck et al. 2008, Le Meur et al. 2009). During 2001 and 2002 Lausanne World Cup  
5 most athletes ran faster over the first kilometre than most other run sections (Vleck et al.  
6 2006, Vleck et al. 2008), while residual effects of prior cycling are the highest and despite the  
7 recommendations of the current literature to adopt an even pacing strategy (*i.e.* constant pace)  
8 for physical events of such duration (for a review, see Abbiss and Laursen 2008). Similarly,  
9 Le Meur et al. (2009) showed that all of the 136 triathletes competing in the 2007 Beijing ITU  
10 WC event adopted a “positive pacing strategy” (whereby speed gradually declines, Abbiss  
11 and Laursen 2008) through the running phase. During this race, the first of the four laps was  
12 run 10.0% faster than the three remaining laps.

13

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

21

22

# 1 MATERIALS AND METHODS

2

## 3 **Participants**

4 Ten well-motivated male triathletes currently competing at a national level and selected on the  
5 basis of their performance time over the short distance triathlon ( $2\text{h}02 \pm 7\text{min}$ ) volunteered to  
6 take part in this experiment. They had trained regularly and competed in triathlons for at least  
7 four years. Their characteristics are presented in Table 1. The triathletes were fully informed  
8 of the content of the experiment, and written consent was obtained before any testing,  
9 according to local ethical committee guidelines (Saint Germain en Laye, France). To  
10 familiarize the triathletes with the cycling and running circuits used in the experiment, a  
11 training camp was programmed 10 days before with a light training program. During the  
12 entire experimental procedure, the subjects did not perform any exhausting exercise in the 48  
13 hours preceding each test.

14

## 15 **Maximal running test**

16 Prior to the experiment, each subject underwent a running test to determine maximal oxygen  
17 uptake ( $\dot{V}O_{2\text{max}}$ ) and ventilatory thresholds (VT1, VT2) on a track where the increment of  
18 speed was fixed at  $1 \text{ km}\cdot\text{h}^{-1}$  each 3 minutes. Oxygen uptake ( $\dot{V}O_2$ ) and expiratory flow ( $\dot{V}_E$ )  
19 were recorded breath by breath with a telemetric gas exchange measurement system (Cosmed  
20 K4b<sup>2</sup>, Rome, Italy). Heart rate values (HR) were monitored every second using a Polar unit  
21 (RS800sd, Polar Electro, Kempele, Finland). Expired gases and HR values were subsequently  
22 averaged every 5 s.  $\dot{V}O_{2\text{max}}$  was determined according to criteria described by Howley et al.

1 (1995) — that is, a plateau in  $\dot{V} O_2$  despite an increase in running speed, a respiratory  
2 exchange ratio value of 1.15, or a Heart rate (HR) over 90% of the predicted maximal HR.  
3  $\dot{V} O_{2max}$  was then determined as the highest value of  $\dot{V} O_2$  achieved during a period of 30-sec.  
4 The first and the second ventilatory thresholds (VT1 and VT2, respectively) were determined  
5 according to criteria previously described by Beaver et al. (1986). VT1 was determined as the  
6 first breakpoint where we detected a systematic increase in  $\dot{V}_E/\dot{V} O_2$  without a concomitant  
7 increase in  $\dot{V}_E/\dot{V} CO_2$ . VT2 was associated with the first breakpoint detected where  $\dot{V}_E/\dot{V} CO_2$   
8 started to increase concomitantly with  $\dot{V}_E/\dot{V} O_2$ .

9

## 10 **Control run**

11 The first test was a 10-km run performed on a 340-m indoor running track (control run, C-  
12 Run). Pacing strategy was left free and the only instruction given to the triathletes was to run  
13 as fast as possible over the 10-km. No-feedback was given about running speeds or split  
14 times. Subjects were informed of each kilometre completed. They had the possibility to drink  
15 250 mL of water at the end of the 3<sup>rd</sup>, the 6<sup>th</sup> and the 9<sup>th</sup> kilometre.

16

## 17 **The three triathlon sessions**

18 All experiments (Fig. 1) were carried out in Paris, specifically at the French National Institute  
19 of Sport and Physical Education (I.N.S.E.P.) from January to March. The study was  
20 conducted on indoor cycling and running tracks. Inside air temperatures ranged from 18° to  
21 20°C. The three experimental triathlons were performed alone (*i.e.* time-trial triathlons) in a  
22 randomized order over the short distance (1.5-km swim, 40-km bike, 10-km run) with a 10-

1 day recovery between them, where training load was minutely controlled. Heart rate at  
2 ventilatory thresholds (VT1, VT2) identified during the maximal running test were used to  
3 demarcate 3 intensity zones (Esteve-Lanao et al. 2007). These included zone 1, low-intensity  
4 exercise performed below VT1; zone 2, moderately high-intensity exercise in an intensity  
5 range between VT1 and VT2; and zone 3, high-intensity aerobic exercise performed above  
6 VT2. In the month prior to the first experimental trial, training durations and distributions of  
7 time spent in the three intensity zones were continuously monitored ( $15 \pm 3$  h.wk<sup>-1</sup> and 79%-  
8 10%-12%, respectively). The mean training load was similar to previous data reported in the  
9 literature for trained triathletes (Hauswirth et al. 1997), high-level runners (Esteve-Lanao  
10 2007), elite rowers (Fiskestrand and Seiler 2004) and cross-country skiers (Seiler and  
11 Kjerland 2006). Throughout the entire experiment all subjects were coached by the same  
12 person. Training load was controlled to be similar in the duration between each test and  
13 similar to the participants usual training pattern. Triathletes were restricted to train in zone 1  
14 during each couple of days following or preceding each test. To avoid injuries or  
15 overreaching, daily feedback was also obtained from triathletes and taken into account.

16 Swimming-cycling phase. The swim was staged in an indoor 50-m pool (24-25°C) wearing a  
17 singlet. The 40-km bike segment was conducted on a cycling track (166m) next to the pool.  
18 The swim-cycle combination was performed in the three experiments at the same speed as the  
19 first triathlon, which was completed as fast as possible. The swimming velocity was  
20 controlled using a pacer placed in the swimming cap (Tempo Trainer, Finis<sup>®</sup>, Helsinki,  
21 Finland), which provided a ring signal each period of time needed for the completion of 12.5-  
22 m. During the first triathlon, they were asked to swim with an even paced strategy. During the  
23 first 3-km of the bike, triathletes had to reach the speed to be maintained during the last 37-  
24 km. A ring signal at each half-lap (83m) indicated precisely the speed they had to keep. The

1 speed of the last 37-km was the one reached from the second to the third kilometre,  
2 considering therefore that the two first kilometres was the distance necessary to reach a  
3 constant speed (Hauswirth et al. 2001). During the cycling sections, triathletes could drink *ad*  
4 *libitum* thanks to 750mL water-bottles disposed on their bikes. The transition time between  
5 swimming-cycling was slightly different from those obtained in competition (*i.e.* 3 minutes).  
6 It included one minute for a change of clothes, one minute for the cardiofrequency meter  
7 installation on the subject and one minute for the run with the bike to reach the cycling track  
8 (200m).

9

10 Running phase. The 10-km run was staged next to the cycling track, on the same indoor  
11 synthetic running track as the C-Run (340m). During the first kilometre, subjects had to  
12 maintain alternatively a running speed 5% faster (Tri-Run<sub>+5%</sub>), 5% slower (Tri-Run<sub>.5%</sub>) and  
13 10% slower (Tri-Run<sub>.10%</sub>) than the mean speed of the C-Run. The subjects were then  
14 instructed to finish the 9 remaining kilometres as quickly as possible, as in a competitive  
15 event. Tri-Run<sub>+5%</sub> condition was representative of the strategy adopted by highly-trained  
16 triathletes in competition during the cycle-to-run transition (Le Meur et al. 2009). Tri-Run<sub>.5%</sub>  
17 and Tri-Run<sub>.10%</sub> were closer to the mean velocity they used to maintain during short distance  
18 triathlon. A ring signal each 25 m indicated precisely the speed the subject had to keep over  
19 the first kilometre. Then, the only instruction given was to run as fast as possible until the  
20 finish line. They were given distance feedback each kilometre completed. During the three  
21 triathlon tests athletes were encouraged to drink 250 mL after 3, 6 and 9 kilometres.

22

23 **Measurement of kinematic variables**

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

7

### 8 **Measurement of metabolic variables**

9 After 35-km of cycling, the subjects were stopped to be equipped with the same portable gas  
10 analyser employed during the running pre-test. Thus, the cycle-to-run transition was reduced  
11 in time in order to reproduce competition conditions (*i.e.* 30s) (Millet and Vleck 2000). The  
12 physiological data ( $\dot{V}O_2$ ,  $\dot{V}_E$ ) were averaged every 5s from the breath-by-breath values. They  
13 were analysed at the beginning (0.5-1 km), in the middle (4.5-5 km) and at the end of each run  
14 (9-9.5 km).

15

### 16 **Blood sampling**

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

20

### 21 **Statistical analyses**

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

7

## 8 RESULTS

9

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

12

13 **Training load.** No significant difference in training volume and training session distribution  
14 in zone1, zone 2 and zone 3 were found between each 10-day period elapsing two tests ( $p =$   
15 0.97).

16

17 **Performances.** No significant difference was observed between the swimming-cycling  
18 phases of the three triathlon sessions ( $p > 0.05$ , Table 2). There was a systematic significant  
19 difference in time required to complete the first 1 km in relation to the starting strategy ( $200 \pm$   
20 15 s,  $190 \pm 14$  s,  $210 \pm 17$  s and  $220 \pm 18$  s for C-Run, Tri-Run<sub>+5%</sub>, Tri-Run<sub>.5%</sub> and Tri-Run<sub>.10%</sub>,  
21 respectively,  $p$  ranging from 0.001 to 0.014). Tri-Run<sub>.5%</sub> resulted in a significantly faster  
22 overall 10-km run performance than Tri-Run<sub>+5%</sub> and Tri-Run<sub>.10%</sub> ( $p = 0.005$  and  $p = 0.02$ ,

1 with Tri-Run<sub>+5%</sub> and Tri-Run<sub>-10%</sub>, respectively) but no significant difference with C-Run ( $p =$   
2 0.58) ( $2028 \pm 78$  s and  $17.8 \pm 0.4$  km.h<sup>-1</sup> vs.  $2000 \pm 72$  s and  $18.0 \pm 0.6$  km.h<sup>-1</sup>,  $2178 \pm 121$  s  
3 and  $16.5 \pm 0.9$  km.h<sup>-1</sup>,  $2087 \pm 88$  s and  $17.2 \pm 0.6$  km.h<sup>-1</sup>, for Tri-Run<sub>-5%</sub>, C-Run, Tri-Run<sub>+5%</sub>  
4 and Tri-Run<sub>-10%</sub>, respectively, Table 2).

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

7 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  
8 lower than their corresponding initial value during Tri-Run<sub>+5%</sub> ( $p = 0.081$  and  $p = 0.085$  for  
9  $\dot{V}O_2$ ,  $p = 0.071$  and  $p = 0.080$  for  $\dot{V}_E$ ,  $p = 0.080$  and  $p = 0.057$  for HR, when considering km-  
10 5 and km-10 with km-1, respectively). On the contrary,  $\dot{V}_E$  and HR were significantly higher  
11 after 5 and 9.5-km than at the beginning of the run for C-Run, Tri-Run<sub>-5%</sub> and Tri-Run<sub>-10%</sub> ( $p$   
12 = 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,  
13 when considering km-5 and km-10 with km-1, for C-Run, Tri-Run<sub>-5%</sub> and Tri-Run<sub>-10%</sub>,  
14 respectively). No significant difference was observed between 5-km  $[La^-]_b$  and corresponding  
15 initial values excepted for Tri-Run<sub>+5%</sub>, whose  $[La^-]_b$  value increased from  $2.9 \pm 0.2$  mmol.L<sup>-1</sup>  
16 to  $4.9 \pm 0.5$  mmol.L<sup>-1</sup> during this period ( $p = 0.035$ ). All final  $[La^-]_b$  values for all the runs  
17 were significantly higher than their corresponding initial values ( $p = 0.014$ ,  $p = 0.021$ , and  $p =$   
18 0.029, for C-Run, Tri-Run<sub>-5%</sub> and Tri-Run<sub>-10%</sub>, respectively).

19

20 Pacing strategy effect. The statistical analysis indicated a significant effect of pacing strategy  
21 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  
22 HR recorded during Tri-Run<sub>+5%</sub> after km-1 were indeed significantly higher than C-Run, Tri-

1 Run<sub>-5%</sub> and Tri-Run<sub>-10%</sub> ( $p < 0.05$ , Table 3). On the contrary,  $\dot{V}O_2$ ,  $\dot{V}E$ , HR and  $[La^-]_b$  during  
2 Tri-Run<sub>-5%</sub> were higher than during the three other conditions after 5 and 9.5-km ( $p < 0.05$ ),  
3 except  $[La^-]_b$  at km-5 ( $p = 0.12$ ). Tri-Run<sub>+5%</sub> demonstrated greater  $[La^-]_b$  at km-5 than C-Run  
4 and the two other triathlon runs ( $p = 0.031$ ,  $p = 0.033$ , and  $p = 0.038$ , when considering C-  
5 Run, Tri-Run<sub>-5%</sub> and Tri-Run<sub>-10%</sub> with Tri-Run<sub>+5%</sub>, respectively).

6

7

## 8 **DISCUSSION**

9

10 The main finding of this study was that a the best initial pacing strategy during the running leg  
11 of a triathlon is to perform the first kilometre 5% slower than the average pace of a 10-km  
12 control run. A 20 sec-variation in running time over the first kilometre led to a significant  
13 difference of  $150 \pm 21$ s on the 10-km triathlon run performance. This result is even more  
14 relevant considering that the differential time at the finish line between the top 10 triathletes  
15 during World Cup triathlons is usually shorter than one minute (Millet and Vleck 2000, Vleck  
16 et al. 2006, Vleck et al. 2008, Le Meur et al. 2009). To our knowledge, this study is the first to  
17 highlight performance improvements by forcing highly-trained athletes to change their usual  
18 pattern of energy expenditure. In previous studies (Hettinga et al 2006, Hettinga et al 2007),  
19 such protocol was always associated with performance decrements.

20

21 In the present study, triathletes significantly increased their 10-km C-Run time by 1.4%, 4.4%  
22 and 8.9% during Tri-Run<sub>-5%</sub>, Tri-Run<sub>-10%</sub> and Tri-Run<sub>+5%</sub>, respectively ( $p < 0.05$ , Fig. 2). The

1 adoption of a fast pace during the first run kilometre induced a significant subsequent  
2 slowdown until the 3<sup>rd</sup> km (the 9 remaining kilometres were performed  $2.7 \pm 0.4 \text{ km.h}^{-1}$   
3 slower than the first one during Tri-Run<sub>+5%</sub>,  $p < 0.01$ ; Fig. 2). Conversely, triathletes  
4 succeeded in increasing their speed by  $1.0 \pm 0.3 \text{ km.h}^{-1}$  over the same section during Tri-Run.  
5 <sub>5%</sub> (Fig. 2).

6

7 The main explanation to elucidate the weaker performance observed during the Tri-Run<sub>+5%</sub>  
8 time-trial is that the pace was centrally down-regulated in a feed-forward manner to avert  
9 premature fatigue during exercise, as already proposed by Ulmer (1996). Tucker (2009) has  
10 recently proposed that alterations in pacing strategy occur to prevent harmful or catastrophic  
11 changes from occurring before the end of exercise, while still optimizing performance. Two  
12 major limiting physiological changes may be identified here; of metabolic and ventilatory  
13 origins respectively.

14

15 The present results revealed a significantly higher metabolic demand during the first  
16 kilometre of Tri-Run<sub>+5%</sub> than during Tri-Run<sub>.5%</sub> and Tri-Run<sub>.10%</sub> (-8.9% and -16.7%  
17 concerning  $\dot{V}O_2$ ; -9.7% and -14.5% concerning  $\dot{V}_E$ , for Tri-Run<sub>.5%</sub> and Tri-Run<sub>.10%</sub>,  
18 respectively;  $p < 0.05$ , Table 3). After 5-km, we still observed a greater anaerobic contribution  
19 for Tri-Run<sub>+5%</sub> than the 2 other strategies in spite of a significantly lower speed ( $4.9 \pm 0.5$   
20  $\text{mmol.L}^{-1}$  and  $16.4 \pm 0.4 \text{ km.h}^{-1}$ ,  $3.8 \pm 0.2 \text{ mmol.L}^{-1}$  and  $18.0 \pm 0.3 \text{ km.h}^{-1}$ ,  $3.6 \pm 0.4 \text{ mmol.L}^{-1}$   
21  $^1$  and  $16.7 \pm 0.4 \text{ km.h}^{-1}$  for Tri-Run<sub>+5%</sub>, Tri-Run<sub>.5%</sub> and Tri-Run<sub>.10%</sub>, respectively;  $p < 0.05$ ;  
22 Table 3). These results are in accordance with previous studies about pacing strategies in  
23 swimming (Thompson et al. 2003), cycling (Foster et al. 1993, Hettinga et al. 2006) and

1 running (Billat et al. 2001), which demonstrated that a fast start induces a higher supply of  
2 anaerobic pathways to achieve a fixed distance. Moreover, Kreider et al. (1988) explained that  
3 the cycle-to-run transition causes a redistribution of blood flow between the different  
4 muscular groups involved during running. The delay in the shunting of blood to the upper  
5 extremities may then increase the rate of glycolysis in both trunk and arms' muscles. Tri-  
6 Run<sub>+5%</sub> may then have induced higher metabolic disturbances through the overall run than  
7 Tri-Run<sub>.5%</sub> and Tri-Run<sub>.10%</sub>.

8

9 Another explanation was that a “negative pacing strategy” (i.e. whereby speed gradually  
10 would have increased) would have generated premature respiratory disturbances during the  
11 cycle-run transition. At the end of the first kilometre of Tri-Run<sub>+5%</sub>, triathletes reached  $93.9 \pm$   
12  $6.1\%$  of  $\dot{V}_{E_{max}}$  determined from the laboratory incremental test. These values were  
13 significantly higher for Tri-Run<sub>+5%</sub> than Tri-Run<sub>.5%</sub> and Tri-Run<sub>.10%</sub> ( $86.5 \pm 7.8\%$  of  $\dot{V}_{E_{max}}$   
14 and  $81.7 \pm 6.9\%$  of  $\dot{V}_{E_{max}}$ , for Tri-Run<sub>.5%</sub> and Tri-Run<sub>.10%</sub>, respectively;  $p < 0.05$ ). Hill et al.  
15 (1991) demonstrated that the crouched position adopted by triathletes during cycling increases  
16 abdominal impedance and diaphragmatic work. Moreover, Boussana et al. (2003) reported  
17 that a moderate intensity cycle-to-run combination, not performed to exhaustion induced a  
18 decrease in respiratory muscle performance. Another study showed that the respiratory  
19 muscle fatigue induced by prior cycling was maintained and not reversed by the subsequent  
20 run (Galy et al. 2003). As triathletes here reached higher running intensity than during these  
21 studies ( $87\% \dot{V}O_{2max}$  vs.  $75\% \dot{V}O_{2max}$ ), Tri-Run<sub>+5%</sub> may have led to greater respiratory  
22 disturbances than Tri-Run<sub>.5%</sub> and Tri-Run<sub>.10%</sub>.

23

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

1

2 Another interesting finding of our study was that the differential time between Tri-Run<sub>-10%</sub>  
3 and Tri-Run<sub>-5%</sub> reached  $59 \pm 11$ s at the end of the race, even if the differential time was  
4 reached at 10s at the end of the first kilometre.  $\dot{V}O_2$ ,  $\dot{V}E$  and  $[La^-]_b$  were significantly lower  
5 after 5 and 9.5-km for Tri-Run<sub>-10%</sub> than Tri-Run<sub>-5%</sub>, suggesting that triathletes didn't succeed  
6 in reaching the maximal workrate they might have been able to sustain. The reason of this  
7 finding remains unclear. Several field-based researches reported that triathletes adopted a high  
8 initial pace during the cycle-to-run transition during both competitions (Vleck et al. 2006,  
9 Vleck et al. 2008, Le Meur et al. 2009) and multi-transition training sessions (Millet and  
10 Vleck 2000). For instance Le Meur et al. (2009) showed that all of the 136 triathletes  
11 competing in the 2007 Beijing ITU WC event adopted a "positive pacing strategy" (whereby  
12 speed gradually declines, Abbiss and Laursen 2008) through the running phase. During this  
13 race, the first of the four laps was run 10.0% faster than the three remaining laps. Then, we  
14 can consider that Tri-Run<sub>+5%</sub> represented the usual strategy experienced by triathletes and that  
15 Tri-Run<sub>-10%</sub> was more distant than Tri-Run<sub>-5%</sub> from triathletes' usual starting strategy. Over  
16 the first kilometre of Tri-Run<sub>-5%</sub> triathletes were forced to start 20 seconds slower than they  
17 used to (*i.e.* Tri-Run<sub>+5%</sub>), whereas this differential starting time reached 35 seconds during  
18 Tri-Run<sub>-10%</sub> (Fig. 2). This finding could be linked with several studies, which have  
19 demonstrated that the pacing strategy is influenced by prior experience (Ansley et al 2004,  
20 Mauger et al., 2009, Micklewright et al. 2009, Foster et al. 2009). A recent research  
21 conducted by Foster et al. (2009) demonstrated that the pattern of energy expenditure during  
22 time trial exercise appears to follow a predetermined template associated with prior  
23 experience, which is modified by a variety of sensory feedbacks mechanisms. From this  
24 perspective, Tri-Run<sub>-10%</sub> may have been more disturbing for triathletes than Tri-Run<sub>-5%</sub> by

1 providing more atypical internal feedbacks than those they usually perceived during the cycle-  
2 to-run transition (see physiological responses in Table 3). The present results suggested that  
3 the higher the sensory feedbacks are modified comparing to prior experience, the more  
4 triathletes had difficulties to adjust their pace. We speculated that triathletes would have taken  
5 benefits particularly from further experimentations of Tri-Run<sub>-10%</sub> strategy to improve their  
6 ability to adjust quickly and to maintain an optimal pace after a slow first kilometre. Indeed  
7 Mauger et al. (2009) have demonstrated recently that cyclists completed a time-trial closed to  
8 their personal best -without any external feedbacks - only if previous experience (*i.e.* at least 4  
9 time trials) has been gained to develop the appropriate optimal strategy. Similarly, Foster et  
10 al. (2009) showed that the “anticipatory-feedback RPE model” is not a non-constant feature  
11 and may require some time to fully develop. Further studies are required to confirm this  
12 hypothesis.

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

24

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6 of this manuscript.

7

8

1 **Conflict of interest**

2 The authors declare that they have no conflict of interest.

3

4 **Ethical standards**

5 The subjects were fully informed of the content of the experiment, and written consent was  
6 obtained before any testing, according to local ethical committee guidelines (Saint Germain  
7 en Laye, France).

8

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9

10

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

6  
7 **FIGURE 2.** Group mean ( $\pm$ SD) values for average running speeds ( $\text{km}\cdot\text{h}^{-1}$ ) recorded every  
8 kilometer during the 10-km run for the Triathlon Runs where the 1<sup>st</sup> km was done  
9 alternatively 5% faster (Tri-Run<sub>+5%</sub>), 5% slower (Tri-Run<sub>-5%</sub>) and 10% slower (Tri-Run<sub>-10%</sub>)  
10 than the Control Run (C-Run): the 9 remaining kilometers were then free in all situations.

11 All values for the Tri-Run<sub>+5%</sub> were significantly different from the corresponding imposed  
12 initial pace (excepted for km-2 value),  $p < 0.01$ .

13 All values for the Tri-Run<sub>-10%</sub> were significantly different from the corresponding imposed  
14 initial pace (excepted for km-5 value),  $p < 0.01$

15 \$ Significantly different within both Tri-Run<sub>+5%</sub> and Tri-Run<sub>-10%</sub>, and within Tri-Run<sub>+5%</sub> and  
16 Tri-Run<sub>-5%</sub>,  $p < 0.05$

17 \* Significantly different within both Tri-Run<sub>-5%</sub> and Tri-Run<sub>-10%</sub>, and within Tri-Run<sub>-5%</sub> and  
18 Tri-Run<sub>+5%</sub>,  $p < 0.05$

19 £ Significantly different within Tri-Run<sub>+5%</sub> and C-Run,  $p < 0.05$

20

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

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

Values are expressed as mean ± SD.

$\dot{V}O_{2\max}$ , maximal oxygen uptake;  $\dot{V}_{E\max}$ , maximal minute ventilation; HR<sub>max</sub>: maximal heart rate.

Perf. Conditions	Swimming time (sec)	Cycling time (sec)	Running time (sec)	Overall time (sec)
C-Run			2000 ± 72 <sup>μμ££</sup>	
Tri-Run <sub>+5%</sub>	1278±54	4260±52	2178 ± 121 <sup>**\$\$μμ</sup>	7716±196 <sup>\$\$μμ</sup>
Tri-Run <sub>.5%</sub>	1275±51	4255±50	2028 ± 78 <sup>££μ</sup>	7558±188 <sup>££μ</sup>
Tri-Run <sub>-10%</sub>	1281±52	4263±57	2087 ± 88 <sup>\$\$£</sup>	7631±191 <sup>£</sup>

**Table 2.** Overall and isolated performances achieved during the three triathlons. Values are expressed as mean ± SD.

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

Significantly different from Tri-Run<sub>+5%</sub>, £  $p < 0.05$ , ££  $p < 0.01$

Significantly different from Tri-Run<sub>.5%</sub>, \$  $p < 0.05$ , \$\$  $p < 0.01$

Significantly different from Tri-Run<sub>-10%</sub>, μ  $p < 0.05$ , μμ  $p < 0.01$

Param. Runs	Oxygen uptake ( $\dot{V}O_2$ ) (mL.min <sup>-1</sup> .kg <sup>-1</sup> )			Expiratory flow ( $\dot{V}_E$ ) (L.min <sup>-1</sup> )			Heart rate (HR) (beats.min <sup>-1</sup> )			Blood lactate ([La <sup>-</sup> ] <sub>b</sub> ) (mmol.L <sup>-1</sup> )		
	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
C-Run	61.5 ±5.1 \$	60.7 ±5.8 \$£	64.4 ±5.7 £\$\$	173. 2± 12.3 \$	179. 8± 14.3 \$\$£	182. 1± 9.5 \$\$£	176.2 ± 17.3 £	186.2 ± 17.9 \$	189.3 ± 18.2 \$\$	0.8 ± 0.3 \$\$ £	3.2 ± 0.4 \$	3.4 ± 0.3 £
Tri-Run <sub>+5%</sub>	66.1 ±7.0 *£	54.9 ±6.8 *££	55.1 ±6.7 ** ££	182. 1± 9.2 *	160. 5± 12.3 **££	162. 1± 13.4 **£	186.0 ± 16.5 *££	176.1 ± 14.8 £*	171.6 ± 12.8 **££	2.9 ± 0.2 *	4.9 ± 0.5 *£	4.1 ± 0.3 £
Tri-Run <sub>-5%</sub>	60.9 ±5.9 \$	65.3 ±5.8 *\$\$	68.1 ±6.8 *\$\$	167. 8± 8.2	187. 9± 11.2 *\$\$	191. 5± 10.8 *\$	168.0 ± 11.2 *\$\$	190.1 ± 14.2 \$	192.8 ± 12.8 \$\$	3.2 ± 0.3 *	3.8 ± 0.2 \$	5.4 ± 0.4 *\$
Tri-Run <sub>-10%</sub>	55.1 ±4.9 *\$\$ £	57.9 ±4.4 \$££	60.6 ±5.7 *£\$	158. 5± 10.8 *\$£	170. 4± 11.2 *££\$	164. 2± 12.1 *££	159.0 ± 11.3 **£\$\$	181.1 ± 17.8 £	180.1 ± 17.2 *£\$	3.1 ± 0.2 *	3.6 ± 0.4 \$	4.0 ± 0.4 £

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

All  $\dot{V}O_2$ ,  $\dot{V}_E$  and HR values for both Tri-Run<sub>-5%</sub> and Tri-Run<sub>+5%</sub> 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<sub>.10%</sub> 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,  $p < 0.05$

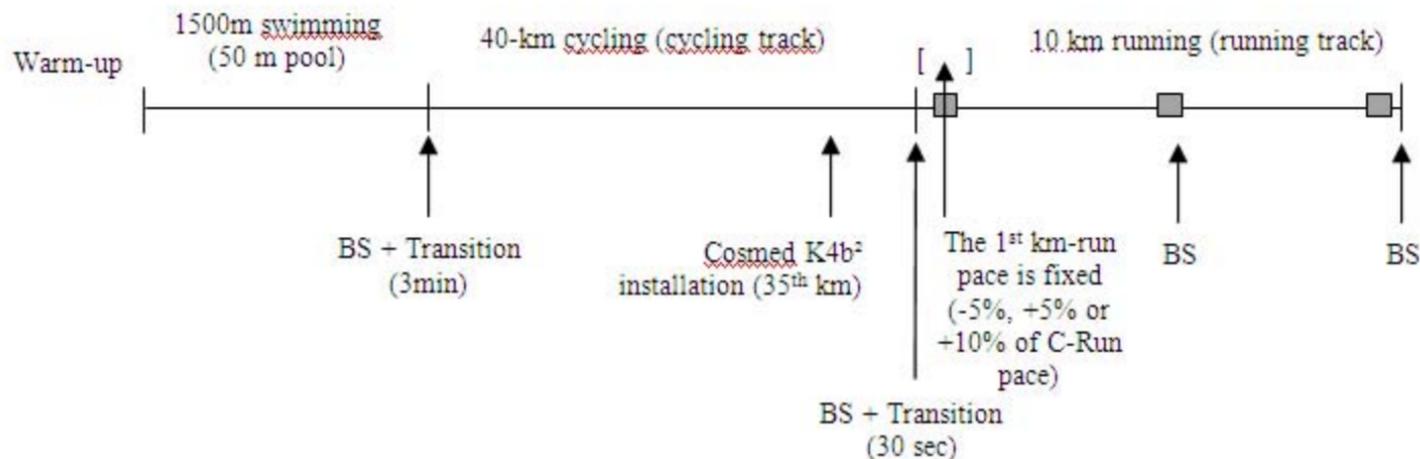
The 5-km  $[La^-]_b$  values for Tri-Run<sub>+5%</sub> were significantly different from the corresponding initial value,  $p < 0.05$

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

Significantly different from Tri-Run<sub>+5%</sub> group, \$  $p < 0.05$ , \$\$  $p < 0.01$

Significantly different from Tri-Run<sub>.5%</sub> group, £  $p < 0.05$ , ££  $p < 0.01$

## Triathlons: 3 modalities of running (T-Run<sub>-5%</sub>, T-Run<sub>+5%</sub> and T-Run<sub>+10%</sub>)



## 10-km Control Run (C-Run)

