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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_{+5%}), 5% slower (Tri-Run_{-5%})
9 and 10% slower (Tri-Run_{-10%}) 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_{-5%} resulted in a significantly faster overall 10-km performance than Tri-
12 Run_{+5%} and Tri-Run_{-10%} ($p<0.05$) 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_{-5%}, C-Run, Tri-
14 Run_{+5%} and Tri-Run_{-10%}, respectively). Tri-Run_{+5%} 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_{-5%} ($p<0.05$).

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 K4b², 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 $\dot{V}O_{2\max}$ 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 3rd, the 6th and the 9th 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 ± 3 h.wk⁻¹ 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[®], 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_{+5%}), 5% slower (Tri-Run_{.5%}) and
13 10% slower (Tri-Run_{.10%}) 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_{+5%} 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_{.5%}
17 and Tri-Run_{.10%} 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⁻¹) 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 ± 14 s, 210 ± 17 s and 220 ± 18 s for C-Run, Tri-Run_{+5%}, Tri-Run_{.5%} and Tri-Run_{.10%},
21 respectively, p ranging from 0.001 to 0.014). Tri-Run_{.5%} resulted in a significantly faster
22 overall 10-km run performance than Tri-Run_{+5%} and Tri-Run_{.10%} ($p = 0.005$ and $p = 0.02$,

1 with Tri-Run_{+5%} and Tri-Run_{-10%}, respectively) but no significant difference with C-Run ($p =$
2 0.58) (2028 ± 78 s and 17.8 ± 0.4 km.h⁻¹ vs. 2000 ± 72 s and 18.0 ± 0.6 km.h⁻¹, 2178 ± 121 s
3 and 16.5 ± 0.9 km.h⁻¹, 2087 ± 88 s and 17.2 ± 0.6 km.h⁻¹, for Tri-Run_{-5%}, C-Run, Tri-Run_{+5%}
4 and Tri-Run_{-10%}, 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_{+5%} ($p = 0.081$ 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_{-5%} and Tri-Run_{-10%} (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_{-5%} and Tri-Run_{-10%},
14 respectively). No significant difference was observed between 5-km $[La^-]_b$ and corresponding
15 initial values excepted for Tri-Run_{+5%}, whose $[La^-]_b$ value increased from 2.9 ± 0.2 mmol.L⁻¹
16 to 4.9 ± 0.5 mmol.L⁻¹ 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_{-5%} and Tri-Run_{-10%}, 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_{+5%} after km-1 were indeed significantly higher than C-Run, Tri-

1 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
2 Tri-Run_{-5%} 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_{+5%} 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_{-5%} and Tri-Run_{-10%} with Tri-Run_{+5%}, 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 ± 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_{-5%}, Tri-Run_{-10%} and Tri-Run_{+5%}, 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 3rd 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_{+5%}, $p < 0.01$; 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 _{5%} (Fig. 2).

6

7 The main explanation to elucidate the weaker performance observed during the Tri-Run_{+5%}
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_{+5%} than during Tri-Run_{.5%} and Tri-Run_{.10%} (-8.9% and -16.7%
17 concerning $\dot{V}O_2$; -9.7% and -14.5% concerning \dot{V}_E , for Tri-Run_{.5%} and Tri-Run_{.10%},
18 respectively; $p < 0.05$, Table 3). After 5-km, we still observed a greater anaerobic contribution
19 for Tri-Run_{+5%} than the 2 other strategies in spite of a significantly lower speed (4.9 ± 0.5
20 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_{+5%}, Tri-Run_{.5%} and Tri-Run_{.10%}, 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_{+5%} may then have induced higher metabolic disturbances through the overall run than
7 Tri-Run_{.5%} and Tri-Run_{.10%}.

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_{+5%}, 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_{+5%} than Tri-Run_{.5%} and Tri-Run_{.10%} ($86.5 \pm 7.8\%$ of $\dot{V}_{E_{max}}$
14 and $81.7 \pm 6.9\%$ of $\dot{V}_{E_{max}}$, for Tri-Run_{.5%} and Tri-Run_{.10%}, 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_{+5%} may have led to greater respiratory
22 disturbances than Tri-Run_{.5%} and Tri-Run_{.10%}.

23

1 Nevertheless, two major observations led us to hypothesise that the weaker performances
2 observed during Tri-Run_{+5%} 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_{+5%} 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_{+5%}. From this perspective the weaker performance achieved
16 during Tri-Run_{+5%} 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⁻¹ per
21 kilometre between kilometre 2 to 4 and only by 0.2 km.h⁻¹ 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_{-10%}
3 and Tri-Run_{-5%} reached 59 ± 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_{-10%} than Tri-Run_{-5%}, 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_{+5%} represented the usual strategy experienced by triathletes and that
15 Tri-Run_{-10%} was more distant than Tri-Run_{-5%} from triathletes' usual starting strategy. Over
16 the first kilometre of Tri-Run_{-5%} triathletes were forced to start 20 seconds slower than they
17 used to (*i.e.* Tri-Run_{+5%}), whereas this differential starting time reached 35 seconds during
18 Tri-Run_{-10%} (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_{-10%} may have been more disturbing for triathletes than Tri-Run_{-5%} 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_{-10%} 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

1 REFERENCES

2 Abbiss CR, Laursen PB (2008) Describing and understanding pacing strategies during
3 athletic competition. *Sports Med* 38:239-52

4 Ansley L, Robson PJ, St Clair Gibson A, Noakes TD (2004) Anticipatory pacing
5 strategies during supramaximal exercise longer than 30 s. *Med Sci Sports Exerc* 36:309-14

6 Beaver WL, Wasserman K, Whipp BJ (1986) A new method for detecting anaerobic
7 threshold by gas exchange. *J Appl Physiol* 60:2020-7

8 Bentley DJ, Millet GP, Vleck VE, McNaughton LR (2002) Specific aspects of
9 contemporary triathlon. *Sports Med* 32:345-359

10 Bernard T, Vercruyssen F, Mazure C, Gorce P, Hausswirth C, Brisswalter J (2007)
11 Constant versus variable-intensity during cycling: effects on subsequent running performance.
12 *Eur J Appl Physiol* 99:103-11

13 Bernard T, Hausswirth C, Le Meur Y, Bignet F, Dorel S, Brisswalter J (2009)
14 Distribution of power output during the cycling stage of a triathlon World Cup. *Med Sci*
15 *Sports Exerc* 41:1296-302

16 Billat VL, Slawinski J, Danel M, Koralsztein JP (2001) Effect of free versus constant
17 pace on performance and oxygen kinetics in running. *Med Sci Sports Exerc* 33:2082-8

18 Boussana A, Matecki S, Galy O, Hue O, Ramonatxo M, Le Gallais D (2001) The effect
19 of exercise modality on respiratory muscle performance in triathletes. *Med Sci Sports Exerc*
20 33:2036-43

21 Esteve-Lanao J, Foster C, Seiler S, Lucia A (2007) Impact of training intensity
22 distribution on performance in endurance athletes. *J Strength and Cond Res* 21:943-9

1 Fiskestrand A, Seiler KS (2004) Training and performance characteristics among
2 Norwegian international elite rowers 1970-2001. *Scand J Med Sci Sports* 14:303-10

3 Foster C, Snyder AC, Thompson NN, Green MA, Foley M, Schrage M (1993) Effect
4 of pacing strategy on cycle time trial performance. *Med Sci Sports Exerc* 25:383-8

5 Foster C, Hendrickson K J, Peyer K, Reiner B, de Koning JJ, Lucia A, Battista RA,
6 Hettinga FJ, Porcari JP, Wright G (in press) Pattern of developing the performance template.
7 *Br J Sports Med*

8 Galy O, Hue O, Boussana A, Peyreigne C, Couret I, Le Gallais D, Mercier J, Préfaut C
9 (2003) Effects of the order of running and cycling of similar intensity and duration on
10 pulmonary diffusing capacity in triathletes. *Eur J Appl Physiol* 90:489-85

11 Gandevia SC (2001) Spinal and supraspinal factors in human muscle fatigue. *Physiol*
12 *Rev* 81:1725-89

13 Gottshall JS, Palmer BM (2002) The acute effects of prior cycling cadence on running
14 performance and kinematics. *Med Sci Sports Exerc* 34:1518–22

15 Hausswirth C, Bigard AX, Berthelot M, Thomaïdis M, Guezennec CY (1996)
16 Variability in energy cost of running at the end of a triathlon and a marathon. *Int J Sports Med*
17 17:572-9

18 Hausswirth C, Bigard AX, Guezennec CY (1997) Relationships between running
19 mechanics and energy cost of running at the end of a triathlon and a marathon. *Int J Sports*
20 *Med* 18:330-9

21 Hausswirth C, Lehénaff D, Dréano P, Savonen K (1999) Effects of cycling alone or in a
22 sheltered position on subsequent running performance during a triathlon. *Med Sci Sports*
23 *Exerc* 31:599-604

1 Hausswirth C, Vallier JM, Lehénaff D, Brisswalter J, Smith D, Millet G, Dreano P
2 (2001) Effect of two drafting modalities in cycling on running performance. *Med Sci Sports*
3 *Exerc* 33:485-92

4 Hausswirth C, Brisswalter J (2008) Strategies for improving performance in long
5 duration events: Olympic distance triathlon. *Sports Med* 38:881-91

6 Hausswirth C, Le Meur Y, Couturier A, Bernard T, Brisswalter J (2009) Accuracy and
7 repeatability of the Polar[®] RS800sd to evaluate stride rate and running speed. *Int J Sports Med*
8 30:354-9

9 Hettinga FJ, deKoning JJ, Broersen FT, Van Geffen P, Foster C (2006) Pacing strategy
10 and the occurrence of fatigue in 4000-m cycling time trials. *Med Sci Sports Exerc* 38:1484-91

11 Hettinga FJ, deKoning JJ, Meijer E, Teunissen L, Foster C (2007) The effect of pacing
12 strategy on energy expenditure during a 1500-m cycling time trial. *Med Sci Sports Exerc*
13 39:2212–18

14 Hill NS, Jacoby C, Farber W (1991) Effect of an endurance triathlon on pulmonary
15 function. *Med Sci Sports Exerc* 23:1260-1264

16 Howley ET, Bassett DR Jr, Welch HG (1995) Criteria for maximal oxygen uptake:
17 review and commentary. *Med Sci Sports Exerc* 27:1292-301

18 Kreider RB, Cundiff DE, Hammett JB, Cortes CW, William KW (1988) Effect of
19 cycling on running performance in triathletes. *Annals of Sports Med* 3:220-225

20 Le Meur Y, Hausswirth C, Dorel S, Bignet F, Brisswalter J, Bernard T (2009) Influence
21 of gender on pacing adopted by elite triathletes during a competition. *Eur J Appl Physiol*
22 106:535-45

1 Mauger AR, Jones AM, Williams CA (2009) Influence of feedback and prior
2 experience on pacing during a 4-km cycle time trial. *Med Sci Sports Exerc* 41:451-58

3 Micklewright D, Papadopoulou E, Swart J Dr, Noakes TD (in press) Previous
4 experience influences pacing during 20-km time trial cycling. *Br J Sports Med*

5 Millet GP, Vleck VE (2000) Physiological and biomechanical adaptations to the cycle
6 to run transition in Olympic triathlon: review and practical recommendations for training. *Br J*
7 *Sports Med* 34:384-90

8 Seiler KS, Kjerland GO (2006) Quantifying training intensity distribution in elite
9 endurance athletes: Is the evidence for an 'optimal' distribution ? *Scand J Med Sci Sports*
10 16:49-56

11 Thompson KG, MacLaren DP, Lees A, Atkinson G (2003) The effect of even, positive
12 and negative pacing on metabolic, kinematic and temporal variables during breaststroke
13 swimming. *Eur J Appl Physiol* 88:438-43

14 Tucker R (2009) The anticipatory regulation of performance: The physiological basis
15 for pacing strategies and the development of a perception-based model for exercise
16 performance. *Br J Sports Med* 43:392-400

17 Tucker R, Noakes TD (2009b) The physiological regulation of pacing strategy during
18 exercise: a critical review. *Br J Sports Med* 43:e1

19 Ulmer HV (1996) Concept of an extracellular regulation of muscular metabolic rate
20 during heavy exercise in humans by psychophysiological feedback. *Experientia* 52:416-20

1 Vercruyssen F, Suriano R, Bishop D, Hausswirth C, Brisswalter (2005) Cadence
2 selection affects metabolic responses during cycling and subsequent running time to fatigue.
3 Br J Sports Med 2002;39:267-72

4 Vleck VE, Bürgi A, Bentley DJ (2006) The consequences of swim, cycle, and run
5 performance on overall result in elite Olympic distance triathlon. Int J Sports Med 27:43-8

6 Vleck VE, Bentley DJ, Millet GP, Bürgi A (2008) Pacing during an elite Olympic
7 distance triathlon: comparison between male and female competitors. J Sci Med Sport 11:424-
8 432

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_{+5%}, Tri-
3 Run_{-5%}, Tri-Run_{-10%} 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 1st km was done
9 alternatively 5% faster (Tri-Run_{+5%}), 5% slower (Tri-Run_{-5%}) and 10% slower (Tri-Run_{-10%})
10 than the Control Run (C-Run): the 9 remaining kilometers were then free in all situations.

11 All values for the Tri-Run_{+5%} 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_{-10%} 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_{+5%} and Tri-Run_{-10%}, and within Tri-Run_{+5%} and
16 Tri-Run_{-5%}, $p < 0.05$

17 * Significantly different within both Tri-Run_{-5%} and Tri-Run_{-10%}, and within Tri-Run_{-5%} and
18 Tri-Run_{+5%}, $p < 0.05$

19 £ Significantly different within Tri-Run_{+5%} 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 ⁻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 $\dot{V}_{E\max}$ (L.min ⁻¹)	184 ± 21
Running HR _{max} (beats.min ⁻¹)	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_{max}: maximal heart rate.

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

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_{+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%}, μ $p < 0.05$, μμ $p < 0.01$

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
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 _{+5%}	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 _{-5%}	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 _{-10%}	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_{-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, $p < 0.05$

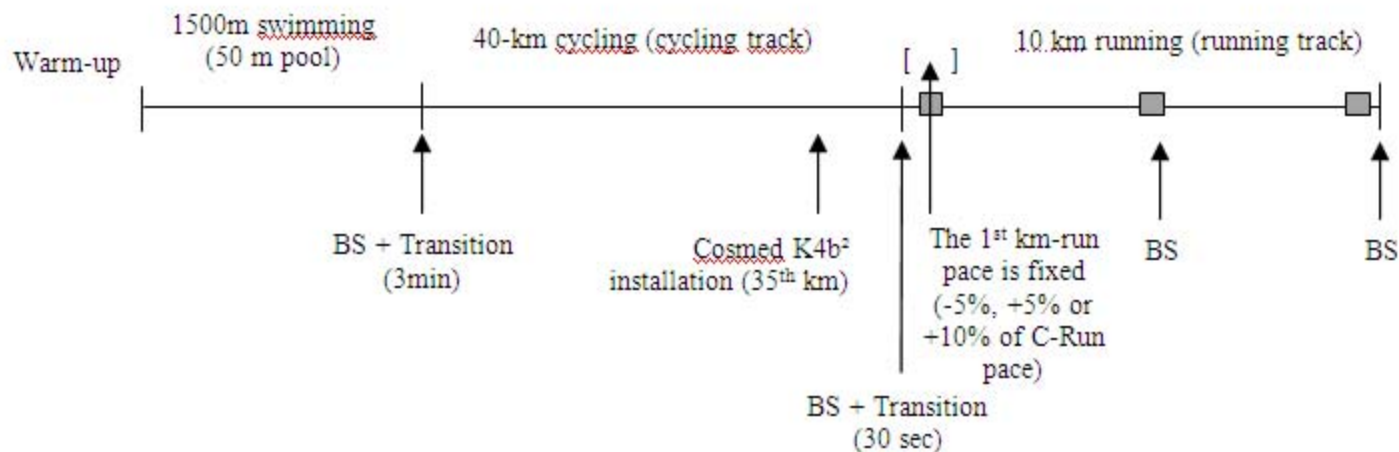
The 5-km $[La^-]_b$ values for Tri-Run_{+5%} were significantly different from the corresponding initial value, $p < 0.05$

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, £ $p < 0.05$, ££ $p < 0.01$

Triathlons: 3 modalities of running (T-Run_{-5%}, T-Run_{+5%} and T-Run_{+10%})



10-km Control Run (C-Run)

