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**TITLE: PHYSIOLOGICAL DEMAND AND PACING STRATEGY DURING THE
NEW COMBINED EVENT IN ELITE PENTATHLETES**

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1 ABSTRACT

2 **Purpose:** To evaluate the physiological demands and effects of different pacing strategies on
3 performance during the new combined event (CE) of the modern pentathlon (consisting of three pistol
4 shooting sessions interspersed by three 1-km running legs).

5 **Methods:** Nine elite pentathletes realised five tests: a free-paced CE during an international
6 competition; an incremental running test to determine $\dot{V}O_{2max}$ and its related velocity ($v\dot{V}O_{2max}$), and
7 three experimental time-trial CE, where the pacing strategy was manipulated (CE_{ref} , $CE_{100\%}$, $CE_{105\%}$).
8 CE_{ref} reproduced the international competition strategy with a 170m fast running start within the first 2
9 kilometres. $CE_{100\%}$ and $CE_{105\%}$ imposed a constant strategy over km-1 and km-2 with a velocity of
10 100% and 105% of the mean speed adopted over the same sections during the international
11 competition, respectively. Km-3 was always self-paced.

12 **Results:** The subjects ran CE_{ref} at $99\pm 4\%$ of $v\dot{V}O_{2max}$ and reached $100\pm 5\%$, $100\pm 7\%$, $99\pm 8\%$ of
13 $\dot{V}O_{2max}$ at the end of kilometres 1, 2, and 3, respectively ($\dot{V}O_{2max}$: $72\pm 6\text{mlO}_2\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$), with a peak
14 blood lactate concentration of $13.6\pm 1.5\text{mmol}\cdot\text{L}^{-1}$. No significant differences in overall performance
15 were found between the pacing conditions ($753\pm 30\text{s}$, $770\pm 39\text{s}$, $768\pm 27\text{s}$ for CE_{ref} , $CE_{100\%}$ and $CE_{105\%}$,
16 respectively, $p=0.63$), but all of the shooting performance parameters were only stable in CE_{ref} .

17 **Conclusion:** Completion of CE by elite pentathletes elicits a maximal aerobic contribution coupled
18 with a high glycolytic supply. Manipulating the mean running speed over km-1 and km-2 had strong
19 influence on the overall pacing strategy and induced minor differences in shooting performance but it
20 didn't affect overall performance.

21
22 **Keywords:** Energetics, Running, Shooting, Olympic discipline

1 INTRODUCTION

2 *Paragraph 1* The modern pentathlon has been an Olympic multidisciplinary sport since 1912. It
3 consists of pistol shooting, fencing, swimming, horse riding events and a 3-km run, all of which are
4 completed in a single day with a recovery period of approximately 1 hour between each event. In
5 2009, the “Union Internationale de Pentathlon Moderne” (UIPM) changed the format of the
6 competition, and decided that the running and shooting disciplines would be carried out in tandem.
7 Specifically, pentathletes will begin the final event with a handicap, and complete three bouts of
8 shooting, with each bout followed by a 1000 m run. In each of the three rounds of firing, athletes must
9 shoot down 5 targets before they begin running. If after 70 seconds, one or more of the five targets has
10 not been hit, the pentathlete can start running the next leg without being further penalized. Considering
11 that the differences between the top half competitors is usually less than 30 seconds at the beginning
12 of the combined event (UIPM database), it is of considerable value for the pentathletes to understand
13 how they can excel in this new discipline, especially in light of the fact that it will be newly
14 introduced during the 2012 London Olympic Games.

15 *Paragraph 2* There are currently no scientific reports that have evaluated the physiological demand of
16 the new combined event. An understanding of the metabolic requirements needed to successfully
17 complete this event would allow the intensity level for this new combined event to be characterized,
18 and allow elite pentathletes to optimize their training programs. In addition, the ability to combine
19 running and shooting in an optimal manner has been proposed as an important determinant of success.
20 Thus, some authors have suggested that pacing strategies may also deserve particular attention (Le
21 Meur et al. 2010). A recent study conducted during a World cup competition (Le Meur et al. 2010)
22 reported that top pentathletes adopt a global “negative pacing strategy” (i.e. negative-split) (Abbiss
23 and Laursen 2008), whereby their speed increases during the last kilometre of the combined event.
24 This tactic may be associated with the assumption that a lower running velocity before the shooting
25 event may result in a better shooting performance by reducing the possible effects of fatigue that are
26 associated with a higher running intensity, as suggested by Le Meur et al. (2010) for elite pentathletes
27 and Hoffman et al. (1992) for elite biathletes.

1 | **Paragraph 3** Le Meur et al. (2010) showed also that pentathletes adopt a “positive pacing strategy”
2 | (i.e. positive split) within each 1000 m run, whereby after peak speed is reached over the first 200 m,
3 | competitors progressively slow down. However, the benefit of this strategy still remains unclear
4 | considering the heterogeneous results reported in the literature. On one hand, several studies showed
5 | that a fast start (ranging between 2 and 5% of the mean running speed over the first 10-25% of the race
6 | distance) is detrimental in some prolonged locomotive events lasting between 2 and 30 minutes, such
7 | as running (Billat et al. 2001b), swimming (Thompson et al. 2003), cycling (Wilberg and Pratt 1988),
8 | and triathlon (Hauswirth et al. 2010). On the other hand, two recent studies reported that a fast start
9 | could also improve performance during 3- and 5-min cycling exercises by speeding $\dot{V}O_2$ kinetics
10 | ([Aisbett et al. 2009](#); [Bailey et al. 2011](#); [Bishop et al. 2002](#)). In the particular context of modern
11 | pentathlon, Le Meur et al. (2010) hypothesized that the fast start systematically observed within each
12 | running kilometre in competition may be related to i) the design of the new shooting-running
13 | combined event, which could perturb the determination of an “optimal” initial running velocity over
14 | each kilometre by inducing frequent variations in running velocity during the event or more positively
15 | to (ii) a potential recovery associated with each shooting session; iii) a strategy to reduce the
16 | deleterious effects of running on the subsequent shooting performance. Nevertheless, each of these
17 | theories are merely hypothetical as there are currently no studies that have investigated which optimal
18 | pacing strategy will lead to the best equilibrium between fatigue within each running leg, and maximal
19 | mean running speed, shooting performance, and hence, global performance during the combined
20 | event. In this perspective, determining the effect of different pacing strategies on shooting and overall
21 | run-shoot performance would be particularly informative, considering that studies on the multi-
22 | disciplinary sports, which share similarities with the combined event (*e.g.* Nordic biathlon) are scarce
23 | (Hoffman et al. 1992).

24 | **Paragraph 4** The first objective of this research was to describe the physiological demands associated
25 | with the new combined shooting-running event performed by elite pentathletes ([Part 1](#)). The second
26 | purpose was to investigate the influence of different pacing strategies on running, shooting, and global
27 | performance, and to describe the concomitant physiological response. To this end, we compared three

1 conditions for which the speed during the first two 1000 m legs were differentially controlled: i) a
2 condition reproducing the competition strategy with a fast start for the first ~200 m (CE_{ref}), ii) a mean
3 constant speed equivalent to CE_{ref} ($CE_{100\%}$), and iii) a higher mean constant speed ($CE_{105\%}$). We
4 hypothesized that $CE_{100\%}$ strategy would be less physically stressful by decreasing the accumulation of
5 fatigue related metabolites and may enhance the mean running speed when compared with CE_{ref}
6 without affecting shooting performance (i.e. Part 2: effect of a fast start strategy within the two first
7 kilometres on performance parameters). Considering that pentathletes are able to increase their speed
8 over the last running leg in competition (Le Meur et al. 2010), we also hypothesized that $CE_{105\%}$ would
9 allow the elite pentathletes to gain substantial time over the two first running legs, what would
10 improve both global running and overall performances, when compared with CE_{ref} and $CE_{100\%}$ (i.e.
11 Part 3: effect of the mean running speed over the two first kilometres on performance parameters).

13 MATERIALS AND METHODS

15 Participants

16 *Paragraph 5* Nine international-level male ($n = 8$) and female ($n = 1$) pentathletes from the French
17 junior and senior modern pentathlon teams were studied. They gave their written informed consent to
18 participate in this investigation, which was conducted according to the Declaration of Helsinki. A local
19 ethics committee for the protection of individuals gave approval concerning the project before its
20 initiation. All the participants were currently engaged in international competitions (World Cup
21 events, European and World Championships) and four of them were medallists during the 2010 World
22 Championships. Their characteristics are presented in Table 1. During the entire experimental
23 procedure, the subjects did not perform any exhausting exercise in the 48 hours preceding each test. A
24 schematic representation of the experimental protocol is provided in Fig. 1.

26 Competition testing

1 **Paragraph 6** Prior to the experiment, data were collected during an international Modern Pentathlon
2 competition organized in Paris, specifically at the French National Institute of Sport, Expertise and
3 Performance (France). The combined event was conducted over a 3060-m distance performed on a
4 340-m indoor running track covered three times during each running leg (3 track laps x 3 running
5 periods, inside air temperature of 18°C). Each of the three legs comprised a 20-m length firing-area
6 and a 1000 m run section.

7 **Paragraph 7** A video acquisition system recording at a frequency of 25 Hz (Sony HDR-CX12
8 AVHD) was posted around the track. It included three digital cameras located 1) at the exit of the
9 shooting range (i.e. start of running: 0-m), 2) at 170-m and 3) on the finish line. Running speed (in
10 km.h⁻¹) was calculated via a subsequent video analysis (Pro suite version 5.0, Dartfish®, Fribourg,
11 Swiss) over the following sections: 0-170m, 170-340m, 340-510m, 510-680m, 680-850m, 850-1000m.

12 **Maximal running test**

13 **Paragraph 8** One week after the competition, the subjects underwent a maximal incremental running
14 test to determine their maximal oxygen uptake ($\dot{V}O_{2\max}$) and the velocity at which $\dot{V}O_{2\max}$ occurred
15 ($v\dot{V}O_{2\max}$) on the same 340-m indoor track. The test began at 12 km.h⁻¹ and the speed was increased
16 by 1 km.h⁻¹ every 3 min until volitional exhaustion. An auditive signal each 20 m indicated precisely
17 the speed the subject had to keep over. Between each increment, blood samples were taken from the
18 participants ear lobes during a 1-min rest period and analyzed using a Lactate Pro system (2000).
19 Oxygen uptake ($\dot{V}O_2$) and expiratory flow (\dot{V}_E) were recorded breath by breath with a telemetric
20 system collecting gas exchanges (Cosmed K4b², Rome, Italy), which was calibrated before each test
21 according to the manufacturer recommendations. Heart rate values (HR) were monitored every second
22 using a Polar unit (RS800sd, Polar Electro, Kempele, Finland). Expired gases and HR values were
23 subsequently averaged every 5 s. $\dot{V}O_{2\max}$ was determined according to criteria described by Howley et
24 al. (1995) - that is, a plateau in $\dot{V}O_2$ despite an increase in running speed, a respiratory exchange ratio

1 value of 1.15 and a HR value over 90 % of the predicted maximal value. The lactate threshold (LT)
2 was assessed according to the D-max method previously described by Cheng et al. (1992).

4 **Experimental combined events**

5 *Analysis of the combined event performed during the international competition*

6 **Paragraph 9** The video analysis performed during the competition testing revealed that the mean
7 running speeds over the first 2 kilometres were not significantly different from each other. Based on
8 this report, the mean running speed adopted over the two first 1 km was calculated for each subject
9 and considered as the reference speed value (v2000ref). The speed value on the first 170 m was
10 significantly higher than the mean running speed over each respective kilometre ($+11.8 \pm 5.8 \%$, $+9.8$
11 $\pm 3.3 \%$ and $+10.1 \pm 4.4 \%$ for km-1, km-2 and km-3, respectively, $p < 0.001$). Except the first 170m
12 segment, no significant difference in running speed were observed between the 5 subsequent sections
13 of each running leg ($p > 0.05$).

15 *The three pacing conditions in running*

16 **Paragraph 10** Analysis of the running speed variations during the international competition allowed
17 the determination of three different pacing strategies, which were performed in a randomised order.
18 The training program was maintained similar throughout the total period of experiments. These three
19 sessions were conducted in the official competition format: 20-m run followed by three shooting-
20 running sessions, in total shooting 15 targets and running 3-km. During each experimental combined
21 event, the running speed was manipulated only during the two first kilometres of the experimental
22 combined events (Fig. 1), in order to evaluate the effect of the pacing strategy over these sections on i)
23 running performance during km-3, ii) shooting performance parameters and iii) overall performance.
24 An auditive signal each 20 m indicated precisely the speed the subject had to keep over and a well-
25 trained experienced runner ran at their side over these sections to help them to adjust their speed to the
26 targeted one. The pentathletes were always instructed to complete the entire last kilometer (i.e. km-3)
27 as fast as possible to maximize performance. The pacing strategy over this section was let free. All

1 experiments (Fig. 1) were carried out on the same indoor track employed for the international
2 competition and the maximal incremental running test (inside air temperatures ranging from 18° to
3 20°C). Before each combined event, pentathletes were required to perform a warm-up session
4 comprising 20 min at 60 % $\dot{V}O_{2max}$ and 4-6 sprints over 30 to 60-m interspersed by 30 s of passive
5 recovery.

7 *Running sessions.*

8 **Paragraph 11** Reference strategy (CE_{ref}). This condition was a simulation of the fast start strategy
9 adopted by the pentathletes during the international competition. Subjects had to adopt a running
10 speed 10% higher than $v_{2000ref}$ over the first 170-m of each of the two first running sections. Then,
11 the running speed was adjusted to 98% of $v_{2000ref}$ over the last 830-m of each of these two first
12 kilometres. Thus, the average running speed imposed over km-1 and km-2 was equal to $v_{2000ref}$.

13 **Paragraph 12** Constant strategies ($CE_{100\%}$, $CE_{105\%}$). The two other conditions imposed a constant pace
14 over the two first kilometres. In the $CE_{100\%}$ condition, the pentathletes were instructed to maintain a
15 running speed corresponding to 100% of $v_{2000ref}$ over km-1 and km-2. In the other condition
16 ($CE_{105\%}$), the running speed was imposed at 105% of $v_{2000ref}$ over the same sections.

17 **Paragraph 13** Mean running speed (in $km \cdot h^{-1}$) was calculated via a subsequent video analysis for km-
18 1 and km-2, using the same methodology employed during the international competition. For the last
19 kilometre (free-paced), the running speed was calculated over the following sections: 0-340m, 340-
20 680m, 680-1000m.

21 **Paragraph 14** Before each combined event, the pentathletes were equipped with the same portable gas
22 analyser employed during the maximal running test. The physiological data ($\dot{V}O_2$, \dot{V}_E) were averaged
23 every 5 s from the breath-by-breath values. Heart rate values (HR) were monitored every second using
24 a Polar unit (RS800sd, Polar Electro, Kempele, Finland). All the data were analysed (i.e. mean value)
25 on time periods corresponded to the last 30 s of run sections and each shooting session. Blood samples
26 were taken from ear lobes 1min after the end of the simulated combined events and each 2min until

1 blood lactate concentration ($[La^-]_p$) decreased, using the same portable blood analyser employed
2 during the incremental running test.

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7 4 *Shooting sessions.*

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9 5 **Paragraph 15** The spatial organisation employed during the competition was reproduced during the
10 simulated combined events. The three shooting rounds (i.e. standing position) were undertaken on a
11 firing area with an individual shooting box. Electronic targets (EasyTargets[®], Competition Level A,
12 Easypenta, France) were composed by one black single aim and 5 green/red lamps to indicate the
13 number of remaining successful shots. The competitors were required to hit 5 times the single target of
14 250 mm diameter within a 59.5 mm diameter. Targets were situated at 10 m from the firing line. The
15 shooting position was left free but the pentathletes were asked to hold the pistol with only one hand,
16 according to UIPM rules. Each pentathlete used his/her own pistol, which was deposited in his box
17 after each shooting session. The latter had to be placed on the table pointing targets, unloaded in an
18 open position.
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32 15 **Paragraph 16** Targets were equipped with a sensing receptor, which was activated when pentathletes
33 succeeded in hitting the target (Scatt USB, Scatt[®], Moscow, Russia). The trigger of each pistol was
34 similarly connected to an electronic pressure-sensitive system, which was activated at each shot (Scatt
35 USB, Scatt[®], Moscow, Russia) with a sampling rate of 100 Hz. Records from the digital targets were
36 used to measure the shooting accuracy (i.e. rate of success in hitting the five targets during each
37 shooting session as a percentage), the shooting time (i.e. the global delay between the first and the last
38 shot of the three shooting sessions) and the shooting delay per attempt (i.e. the mean period of time
39 between two consecutive shots). The transition time on the shooting range was also calculated by
40 deducting the shooting time from the time spent on the shooting range. All the variables were
41 considered for each running lap or each shooting session individually and also pooled for the entire
42 race. Because the first shooting session preceded the first running section, where the pacing strategy
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1 was manipulated, the shooting data presented in the manuscript will distinguish the results for the
2 whole event and only for the shooting sessions 2 and 3.

3 4 5 6 **Statistical analyses**

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9 **Paragraph 17** Statistical analysis was performed using the SPSS 19 package (IBM corporation, Inc.
10 New York, USA). All variables were expressed as mean and standard deviation (Mean \pm SD). The
11 level of significance was set at $p < 0.05$. We assessed the distribution of the analysed variables using a
12 Shapiro-Wilk test. For overall performance, running performance, transition time and physiological
13 parameters, the results showed that the distributions respected a normal distribution. Then, a two-way
14 analysis of variance (pacing strategy x running section) for repeated measures was performed to
15 analyse the effects of the running section and the pacing strategy on running speed, HR, $\dot{V}O_2$ and \dot{V}_E
16 values as dependent variables. A Tukey *post hoc* test was used to determine differences among all
17 pacing strategies and periods during exercise. A pair t-test was performed to compare overall
18 performance between the international competition and CE_{ref}. For the shooting parameters (shooting
19 time, shooting accuracy and delay per shot), the distributions deviated from normal distribution, so a
20 non parametric Friedman's rank test was undertaken to assess the statistical differences between
21 conditions for each shooting session (S1, S2, S3) and to evaluate the statistical differences in time for
22 each pacing strategy. When a significant F-value in Friedman's analysis was found, a *post hoc* test was
23 used to determine the between-means differences. Effect size [standardized difference or Cohen's d
24 (Cohen 1988)] was also used, where appropriate, to evaluate differences. Thresholds for small,
25 moderate, and large effects were 0.20, 0.50, and 0.80, respectively (Cohen 1988).
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49 **RESULTS**

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54 **Paragraph 18** All pentathletes completed the protocol and succeeded to conform the pacing strategies
55 imposed over the two first kilometres at ± 0.2 km.h⁻¹. Table 2 depicts the results concerning
56 performance for the three combined event conditions. No significant difference on overall
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1 performance was observed between CE_{ref} and the international competition ($p = 0.38$). The same result
2 was observed when considering the three experimental conditions ($p = 0.63$), even when the first
3 shooting session was excluded from the analysis ($p = 0.53$).

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5 **Paragraph 19 Running performance.** Figure 2 (panel A) presents the evolution of the mean running
6 speed during the three conditions. The statistical analysis indicated a significant interaction effect
7 (pacing condition x running section) on running performance ($p < 0.001$).

8 **Paragraph 20 Time period effect.** No significant difference in running speed were reported between
9 km-1 and km-2 for CE_{ref} ($p = 0.39$), $CE_{100\%}$ ($p = 0.93$) and $CE_{105\%}$ ($p = 0.15$). A significant increase in
10 running speed was observed in km-3 for both CE_{ref} ($p = 0.003$) and $CE_{100\%}$ ($p < 0.001$, effect size =
11 0.75). The last kilometre was run slower than km-2 in $CE_{105\%}$ ($p < 0.001$, effect size = 2.22). The
12 running speed was significantly lower over the section [340-680m] than over the sections [0-340m]
13 and [680-1000m], for the three conditions ($p < 0.01$). While the running speed was lower over [680-
14 1000m] than over [0-340m] in $CE_{105\%}$ ($p < 0.05$), no significant difference was reported in the two
15 other conditions, when comparing these two sections of km-3 in CE_{ref} and $CE_{100\%}$.

16 **Paragraph 21 Pacing strategy effect.** Non-significant difference in total running time and mean
17 running over the 3-km were observed between the three conditions ($p = 0.81$, Table 2). There was a
18 systematic significant difference in running speed over the first 2 km in relation to the starting strategy
19 when comparing $CE_{105\%}$ with CE_{ref} ($p = 0.02$ and $p = 0.05$ for km-1 and km-2, respectively) and
20 $CE_{100\%}$ ($p < 0.001$ and $p = 0.05$ for km-1 and km-2, respectively). The running speed over km-3 was
21 lower in $CE_{105\%}$ than in CE_{ref} ($p < 0.001$, effect size = 1.33) and in $CE_{100\%}$ ($p < 0.001$, effect size =
22 1.77). The running speed was significantly lower over each sections of km-3 in $CE_{105\%}$ than in CE_{ref}
23 and $CE_{100\%}$ ($p < 0.001$), while no significant difference was reported between CE_{ref} and $CE_{100\%}$.

24 **Paragraph 22 Shooting performance.** Figure 2 (panel B-D) describes the evolution of the shooting
25 performance parameters throughout the three sessions and for each of the three conditions.

26 **Paragraph 23 Time period effect.** No significant difference was observed between the three shooting
27 sessions for CE_{ref} , when considering the shooting time ($p = 0.20$), the shooting accuracy ($p = 0.25$) and

1 the delay per shot between the three shooting sessions (Friedman ANOVA, $p = 0.06$). During CE_{100%},
2 no significant difference was observed between the three sessions for the shooting time ($p = 0.24$) and
3 the shooting accuracy ($p = 0.85$). A significant increase in delay per shot was observed when
4 comparing S1 and S3 ($p = 0.03$, effect size = 0.61). During CE_{105%}, the shooting time increased during
5 S3 ($p = 0.01$, effect size = 0.91) because of a non significant tendency of the shooting accuracy to
6 decrease ($p = 0.07$) and a significant increase of the delay per shot ($p = 0.03$, effect size = 0.76).

7 **Paragraph 24 Pacing strategy effect.** No significant difference was observed between the three
8 conditions when comparing shooting time for the whole combined event ($p = 0.65$), even when
9 excluding the first shooting session ($p = 1.00$). A similar result was observed by considering each
10 shooting session individually ($p = 0.96$, $p = 0.27$, $p = 0.37$ for S1, S2, S3, respectively). Shooting
11 accuracy values were not significantly different between the three conditions when considering the
12 whole combined event ($p = 0.95$), S2 and S3 together ($p = 0.87$), and each shooting session
13 individually ($p = 0.60$, $p = 0.52$, $p = 0.47$, for S1, S2, S3, respectively). A similar result was reported
14 concerning the delay per shot for whole combined event ($p = 0.60$), the two last shooting sessions ($p =$
15 0.85) and each session individually ($p = 0.70$, $p = 0.46$, $p = 0.90$, for S1, S2, S3, respectively).

16 **Paragraph 25 Transition time.** No significant difference in the transition time was observed between
17 the three conditions (29 ± 6 s, 30 ± 5 s and 32 ± 5 s, for CE_{ref}, CE_{100%} and CE_{105%}, respectively, $p =$
18 0.44).

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20 **Paragraph 26 Physiological parameters.** Table 3 indicates mean values for HR, $\dot{V}O_2$, \dot{V}_E and blood
21 lactate accumulation for the running bouts. CE_{ref} was performed at $100 \pm 5\%$ $\dot{V}O_{2max}$, $99 \pm 4.3\%$
22 $v \dot{V}O_{2max}$ and $96 \pm 3\%$ HR_{max} (Fig. 3). The statistical analysis indicated a significant interaction effect
23 (period time x pacing strategy) on HR ($p = 0.02$) and \dot{V}_E values ($p = 0.02$), but no effect on $\dot{V}O_2$
24 values ($p = 0.13$).

25 **Paragraph 27 Time period effect.** A significant increase in HR values was observed for both CE_{ref}
26 after km-1 ($p < 0.001$, effect size = 1.33) and after km-2 ($p < 0.001$, effect size = 1.90). Similar results

1 were reported for CE_{100%} ($p < 0.001$, effect size = 2.36). A significant difference was reported for
2 CE_{105%} between km-1 and km-2 ($p = 0.02$, effect size = 2.32), but not between km-2 and km-3 ($p =$
3 0.25). \dot{V}_E values increased throughout the combined event for CE_{ref} ($p < 0.01$) and CE_{100%} ($p < 0.05$)
4 with large effect sizes (>1.0). During CE_{105%}, \dot{V}_E values increased only after the first kilometre ($p <$
5 0.01, effect size = 1.29).

6 **Paragraph 28 Pacing strategy effect.** HR values were significantly lower in CE_{105%} than in the two
7 other conditions during km-3 ($p < 0.05$, effect sizes > 0.80). Significant higher \dot{V}_E values in
8 CE_{105%} were reported during km-1 and km-2, when compared with CE_{ref} and CE_{100%} values ($p < 0.05$,
9 effect sizes < 0.50), but not during km-3 ($p > 0.05$). No effect of pacing strategy on HR and \dot{V}_E values
10 was observed when comparing CE_{ref} and CE_{100%} at any period of the combined event ($p > 0.05$). No
11 significant effect of pacing strategy was observed on $[La^-]_b$ values at the end of the combined event (p
12 = 0.29).

15 DISCUSSION

16 **Paragraph 29** The purpose of the present study was to assess the physiological demands associated
17 with the shooting-running event of the modern pentathlon, which will be introduced in the 2012
18 Olympic Games. To this end, a simulated shooting-running event was performed by elite pentathletes.
19 Secondly, our research examined the physiological responses associated with three different pacing
20 strategies, and observed the effect of these strategies on overall performance. The most important
21 findings were as follows: (i) the completion of the combined event was performed close to $v \dot{V}O_{2max}$
22 and characterized by an increase of running speed over the last kilometre, leading to a maximal
23 aerobic demand and a high anaerobic contribution (Part 1); (ii) the absence of any significant effect of
24 the start strategy within km-1 and km-2 on the performance parameters (Part 2); (iii) running above
25 $v \dot{V}O_{2max}$ over the first two kilometres had no significant effect on overall performance but resulted in
26 a subsequent decrease of performance during the last shooting-running combination (Part 3).

1
2 ***Part 1: Physiological demand of the combined event***

3 **Paragraph 30** All the pentathletes involved in the present study used a positive-split strategy during
4 each kilometre of the international competition, whereby their running speed decreased after an
5 aggressive 170 m start. In addition, they all ran the last kilometre faster than the first two. The
6 pentathletes succeeded in reproducing this strategy during the CE_{ref} condition, which was consistent
7 with the results reported by Le Meur et al. (2010) during the 2009 Budapest World Cup event. As a
8 result, we considered $\dot{V}O_2$, $\dot{V}E$, HR and $[La^-]_b$ recorded during CE_{ref} as being representative of the
9 metabolic physiological demands associated with the new combined event in high level pentathletes.
10 This assumption was strengthened by the absence of significant difference in overall, running and
11 shooting performances between the international competition and CE_{ref}. The observation of elevated
12 values on fractions of HR_{max} ($96 \pm 3 \%$) and $\dot{V}O_{2max}$ ($100 \pm 5 \%$ $\dot{V}O_{2max}$) indicated that the completion
13 of this new Olympic discipline is highly demanding for the aerobic pathway (Fig. 3). These results
14 confirmed that the run in modern pentathlon is completed in the severe intensity domain (Hill et al.
15 2002), as suggested by Whyte and James (2007). This finding may explain the high $\dot{V}O_{2max}$ values
16 measured in the high level pentathletes engaged in the present study (72 ± 5 mL O_2 .min⁻¹.kg⁻¹), which
17 reflect those already reported in elite [biathletes \(Rundell and Bacharach 1995\)](#), runners (Billat et al.
18 2001a), and triathletes (Le Meur et al. 2009). Considering the fact that $\dot{V}O_{2max}$ values were
19 significantly lower than the values reported on both elite runners (Billat et al. 2001a) and triathletes
20 (Le Meur et al. 2009) of the same calibre, it is possible that elite pentathletes may demonstrate lower
21 running economy than other endurance athletes. This finding may be attributed to the variety of
22 pentathlon disciplines, which may result in a relative lack of specific training focus for running.

23 **Paragraph 31** Interestingly, the results of the present study were in line with the mean values of 99%
24 HR_{max} and 95% $\dot{V}O_{2max}$ measured by Duffield et al. (2005) during a maximal 3000 m run in trained
25 track athletes (when considering the whole race). $[La^-]_b$ values at the end of CE_{ref} were similar to peak

1 values reported by Shave et al. (2001) in trained athletes after a maximal 3000 m run (13.6 ± 1.5
2 mmol.L^{-1} in the present study vs. $15.9 \pm 2.1 \text{ mmol.L}^{-1}$ for Shave et al. 2001). Taken together, these
3 results demonstrate that elite pentathletes will benefit from developing comparable physiological
4 abilities to 3000 m track runners in preparing for the combined event. However, because $\dot{V}O_2$ values
5 dropped to 65% of $\dot{V}O_{2\text{max}}$ after shooting sessions 2 and 3 (results not presented), it is likely that the
6 new combined event may accentuate the necessity to reach $\dot{V}O_2$ values near $\dot{V}O_{2\text{max}}$ in a short delay
7 (Fig. 3). In addition, it is interesting to note that the increase in running speed over km-3
8 systematically observed by Le Meur et al. (2010) was clearly confirmed in the present study (+6.9%
9 and +6.0% between km-2 and km-3 in Le Meur et al. (2010) and in the present study, respectively,
10 Fig. 2A). Considering that $\dot{V}O_2$ values did not increase during the 3rd kilometre (i.e. the subjects had
11 reached $\dot{V}O_{2\text{max}}$ during km-2, Table 3), it suggests that elite pentathletes may also benefit from
12 improving their anaerobic capacity, so that they may be able to reach speeds above $\dot{V}O_{2\text{max}}$ over the
13 last kilometre in order to win or attain better placement on the finish line.

15 ***Pacing strategy***

16 *Part 2: Effect of a fast start strategy within the two first kilometres on performance parameters*

17 ***Paragraph 32*** The first hypothesis of the present study was that the positive pacing strategy adopted
18 by the elite pentathletes within the two first kilometres of the international competition investigated in
19 the present study (+10.8 % over the initial 170 m of km-1 and km-2) may have led to suboptimal
20 performance. Due to the fact that previous studies have shown that a positive pacing strategy may be
21 associated with early fatigue (Billat et al. 2001b; Hausswirth et al. 2010; Le Meur et al. 2011; Wilberg
22 and Pratt 1988), we suggested that a constant pacing strategy over km-1 and km-2 (associated with
23 potential lower anaerobic contribution at the beginning of the two first kilometres, i.e. $CE_{100\%}$
24 condition) would result in an improved shooting performance and a higher running speed over the last
25 kilometre, when compared with the competition strategy (i.e. CE_{ref} condition). Interestingly, our

1 results did not confirm this hypothesis, while the running speed during CE_{ref} was $2.0 \text{ km}\cdot\text{h}^{-1}$ higher
2 over the first 170 m of km-1 and km-2 than in $CE_{100\%}$. Indeed, no significant difference on running
3 speed over km-3, shooting time and overall performance were reported when comparing CE_{ref} and
4 $CE_{100\%}$ (Table 2).

5 **Paragraph 33** Interestingly, heart rate, $\dot{V}O_2$, and \dot{V}_E responses at the end of the first two kilometres
6 were similar in CE_{ref} and $CE_{100\%}$, suggesting that the manipulation of the initial running speed did not
7 affect the aerobic response during the run, or at the beginning of each shooting session (Table 3). The
8 absence of $[La^-]_b$ measurements after each kilometre made it difficult to discuss the evolution of
9 anaerobic contribution during the two conditions. However, no significant differences were reported
10 between CE_{ref} and $CE_{100\%}$ of the peak value reached after the completion of the combined event,
11 suggesting a relatively similar global glycolytic supply for these two strategies. In the same time, all
12 shooting performance parameters (time, accuracy, and delay per shot) remained stable throughout the
13 combined event only in the CE_{ref} condition. Indeed, while both shooting time and shooting accuracy
14 did not reveal any significant variation in $CE_{100\%}$, a small increase in the delay per shot was observed
15 during the third shooting sessions (Fig. 2D). Taken together, these results suggested that the fast start
16 pacing strategy classically used by pentathletes in competition within each running sections does not
17 appear to have a negative effect on the performance of the new shooting-running combined event.

18 Part 3: Effect of the mean running speed over the two first kilometres on performance parameters

19 **Paragraph 34** The second hypothesis of the present study was that the adoption of a higher mean
20 running speed over km-1 and km-2 (i.e. $CE_{105\%}$) would improve overall running performance, without
21 compromising shooting time, when compared with CE_{ref} and $CE_{100\%}$. Nevertheless, no significant
22 differences in overall performance or global shooting or running times were reported between $CE_{105\%}$
23 and the two other conditions (Table 2). While a significant increase in running speed was reported
24 over km-3 for both CE_{ref} and $CE_{100\%}$, setting running speeds above $v\dot{V}O_{2max}$ over the two first
25 kilometres during $CE_{105\%}$ (102% and 101% $v\dot{V}O_{2max}$, over km-1 and km-2, respectively) resulted in

1 global positive pacing for all nine pentathletes, whereby the running speed decreased by 8% over the
2 last kilometre (-1,5 km.h⁻¹, +22 s, Fig. 2A). Considering the fact that no significant differences in
3 oxygen consumption was observed between the three conditions during km-1 and km-2, it suggested
4 that the completion of these sections during CE_{105%} was related to i) a faster oxygen kinetic than Ceref
5 and CE_{100%}; ii) a greater glycolytic contribution; or iii) both. The absence of significant difference in
6 final peak [La-]_b, despite a slower pace over the last kilometre in this condition confirmed that the
7 pentathletes may have increased the mobilization of their anaerobic reserve during the two first
8 kilometres of CE_{105%}. This hypothesis may explain i) the slowdown observed over the last kilometre
9 only in this condition and ii) the lower speed reported over each sections of km-3 in CE_{105%}, than in the
10 two other conditions. Collected together, these results confirmed that the development of a high
11 anaerobic capacity may represent a factor of performance in the new combined event for elite
12 pentathletes. Besides, a more detailed analysis of the pacing strategy adopted over km-3 revealed a fast
13 start coupled with a systematic endspurt (i.e. U-shaped pacing strategy) in all the experimental
14 conditions. This finding showed that pacing strategy was altered continuously throughout the last
15 kilometre, whatever the strategy employed, possibly in response to changing afferent signals but also
16 to a possible attempt to reduce the deleterious effects of fatigue on running.

17 **Paragraph 35** No significant differences were reported between the three conditions for the shooting
18 performance. However, the results revealed a tendency of CE_{105%} to reveal a weaker performance,
19 when compared to CE_{ref} and CE_{100%} ($p = 0.11$) and a significant increase in shooting time during the
20 third shooting session was observed only for CE_{105%} (+12 s, +25%), suggesting that CE_{105%} may be
21 more stressful for pentathletes during the last shooting session (Fig. 2B). This decrease in shooting
22 performance was explained by a significant increase in the delay per shot and a non significant
23 tendency of shooting accuracy to decrease during the same period ($p = 0.07$) (Fig. 2C, D). This finding
24 was consistent with the reverse U-shape relationship classically reported in the literature when
25 considering the reciprocal influence of physical exercise level and psycho cognitive process
26 (Brisswalter et al. 2002). Even the present results should be taken with caution considering the
27 absence of systematic statistical significant differences in overall and shooting performances, they

1 suggested that the higher energy expenditure associated with CE_{105%} during km-1 and km-2 may have
2 been deleterious for the visual and/or psychosensorial mechanisms involved by the shooting task.
3 Despite it was already verified in elite biathletes (Hoffman et al. 1992), this hypothesis required
4 further investigations in the context of high-level modern pentathlon.

5 **Paragraph 36** In conclusion, the physiological demands of the new combined shooting-running event
6 of the modern pentathlon corresponds to 3 running bouts performed at $100 \pm 5\% \dot{V}O_{2max}$, $99 \pm 4.3\%$
7 $v\dot{V}O_{2max}$ and $96 \pm 3\%$ HR_{max}, interspersed by a transitional shooting period of almost 35 sec. In this
8 context, and considering the high values of $\dot{V}O_{2max}$ of this elite population ($72.5 \text{ mlO}_2 \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$), this
9 first analysis of the new combined event suggests that the energy demand is very high and mainly
10 supplied by aerobic metabolism. The participation of the anaerobic pathway does not seem to be
11 negligible considering that both the spontaneous high running pace over the last 1 km section (103%
12 $v\dot{V}O_{2max}$), and the high peak $[\text{La}^-]_b$ values reached at the end of the combined event. Additionally, the
13 present results revealed that minor differences in mean running speeds imposed over the first two first
14 kilometres between CE_{ref} and CE_{105%} ($\sim 0.6 \text{ km} \cdot \text{h}^{-1}$) greatly influence the pacing adopted during the
15 event as a whole by modifying the global strategy (negative vs. positive pacing) without influencing
16 overall performance. Since each failed shot takes approximately 6 sec to make-up over a 1-km section
17 ($+0.6 \text{ km} \cdot \text{h}^{-1}$ in the range of speeds observed in international modern pentathlon competitions),
18 improving the intrinsic shooting performance level, and the ability to shoot under both pressure and
19 fatigue, may constitute the best way to optimize the performance level of elite pentathletes in the new
20 combined event in the short term (in the perspective of 2012 London Olympic Games). This
21 assumption is consistent with the results reported by Le Meur et al. (2010), which showed that clear
22 rounds were scarce during a World Cup competition, and the best performers in the combined event
23 distinguished themselves due to their greater shooting performance. Elite pentathletes should consider
24 these findings for planning their physical training programs, notably in the perspective of the 2012
25 London Olympic Games.

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2
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4
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6
7 4 cooperation.
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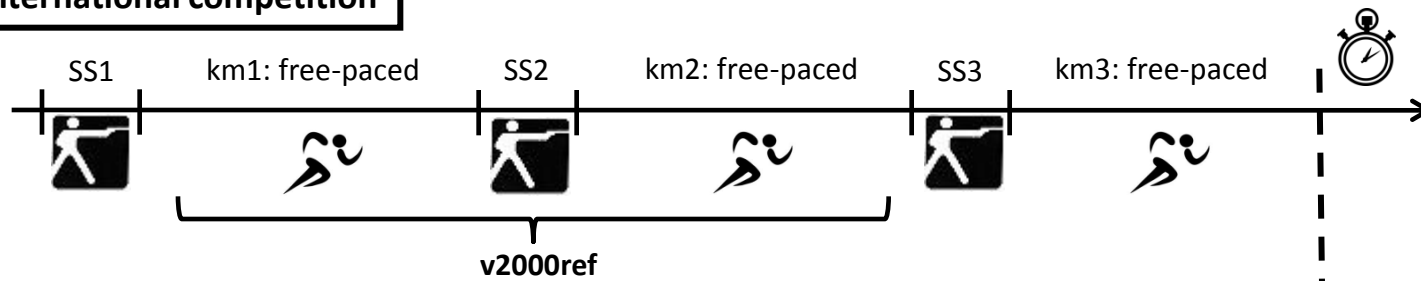
1 **FIGURE 1.** Schematic representation of the experimental protocol. The evolution of running speed
2 was analysed during the combined event of an international competition in nine elite pentathletes, who
3 subsequently completed three time-trial combined events in a randomized order. The reference
4 combined event (CE_{ref}) reproduced the strategy adopted during the competition with a 170m fast
5 running start within the first 2 kilometres. In the two other conditions, km-1 and km-2 were run at a
6 constant velocity of 100% ($CE_{100\%}$) or 105% ($CE_{105\%}$) of the mean speed adopted over the 2 first km of
7 the international competition. Km-3 was always self-paced. Grey portions: $\dot{V}O_2$, $\dot{V}E$, HR interval
8 measurements; dark drops: blood samples. RS: running section, SS: shooting session.

10 **FIGURE 2 (a, b, c, d).** Mean (\pm SD) running velocity ($km \cdot h^{-1}$), shooting time (s), shooting accuracy
11 (% of success) and delay per shot (s) for the three pacing conditions. *Significantly different from
12 km-1, $p < 0.05$. #Significantly different from km-2, $p < 0.05$. #Significantly different from CE_{ref} and
13 $CE_{100\%}$, $p < 0.05$.

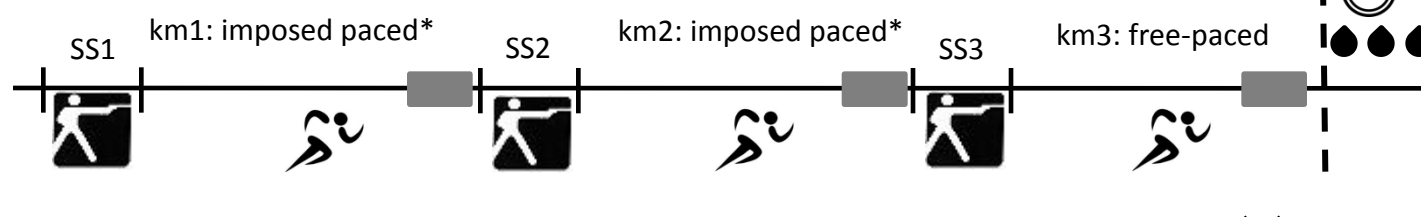
15 **FIGURE 3.** Example of HR (grey line) and $\dot{V}O_2$ (black line) evolutions during the reference
16 combined event for one male pentathlete. Dashed lines represent maximal values reached during the
17 maximal incremental running test.

Figure 1

International competition



Experimental conditions



- Overall performance
- Shooting performance (time, accuracy, delay per shot)
- Running time
- HR, VO_2 , $V_{E'}$, [La⁻]

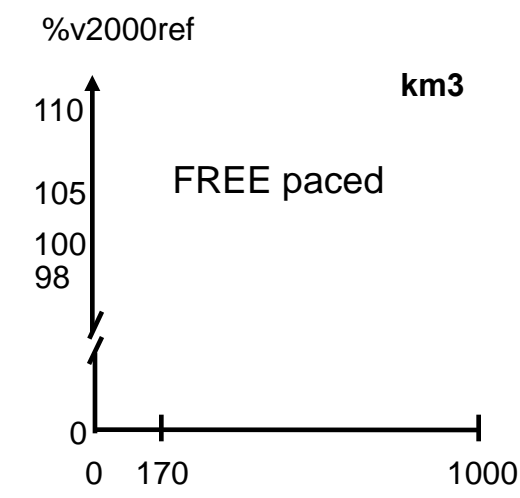
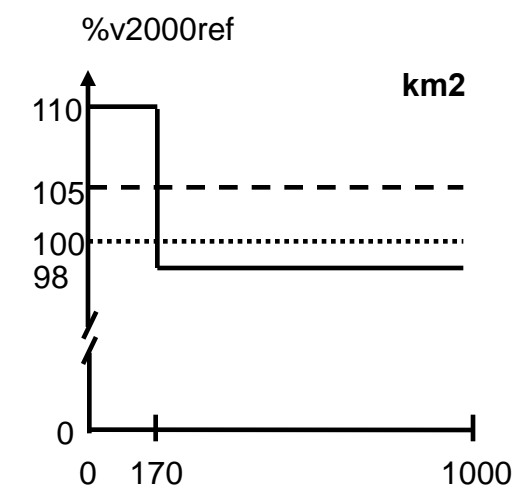
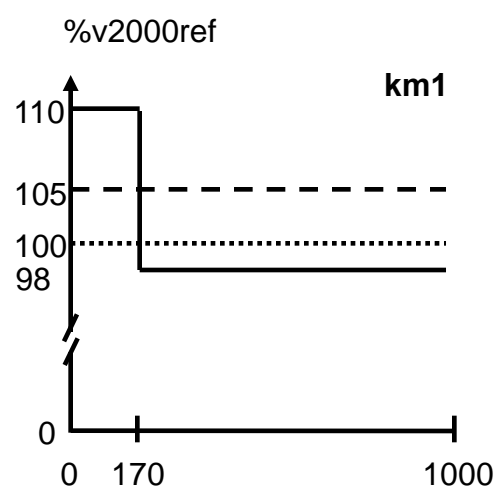
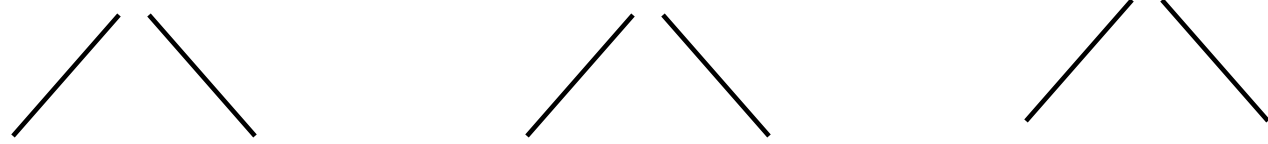


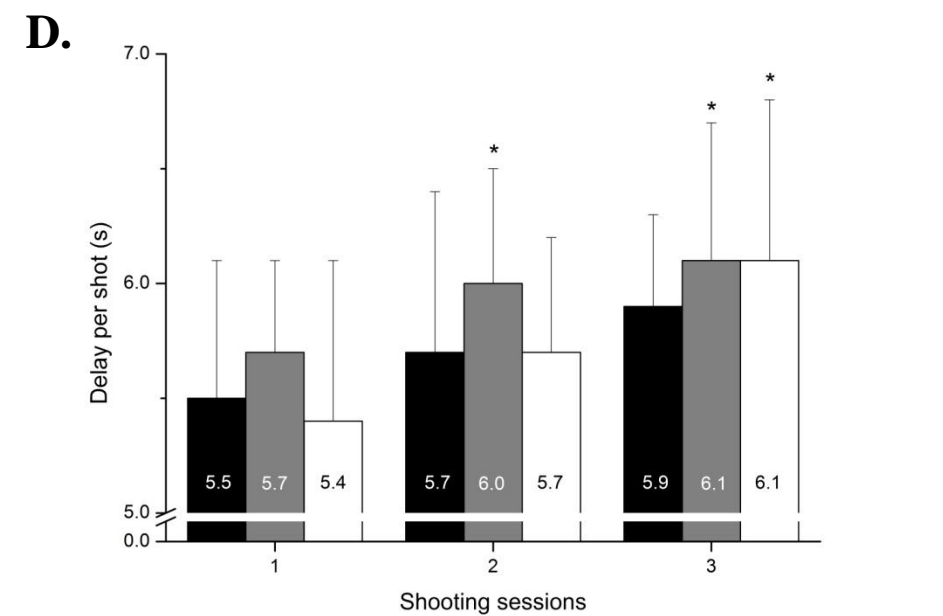
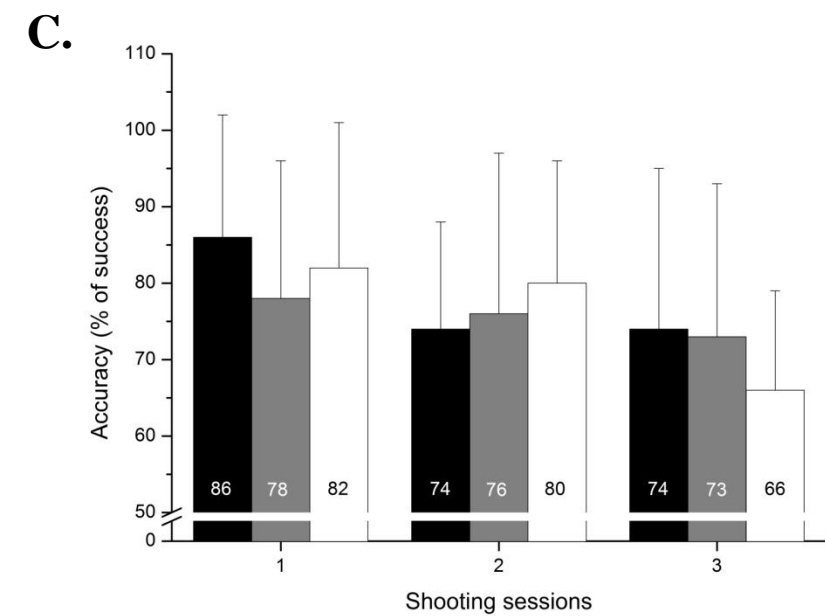
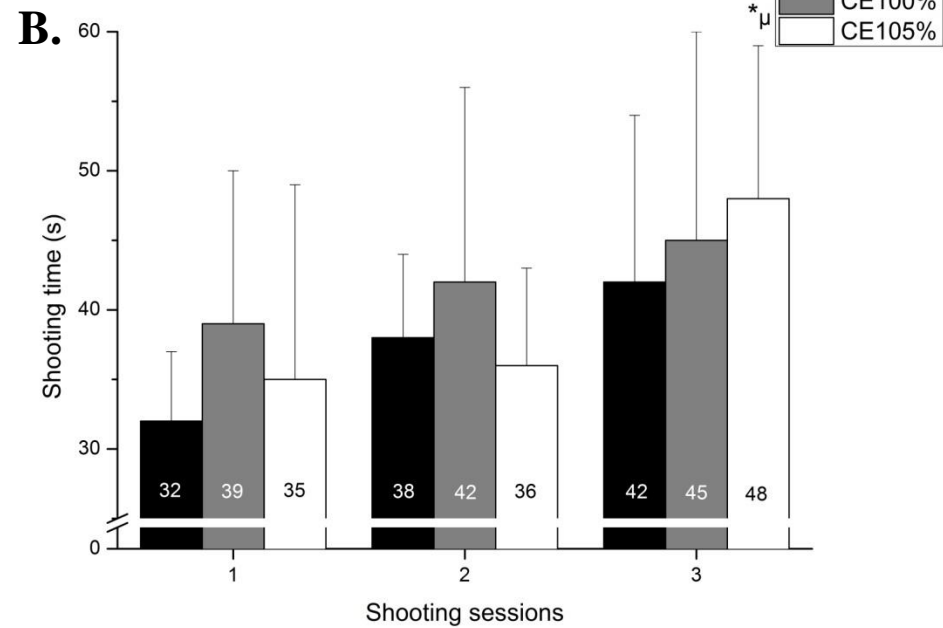
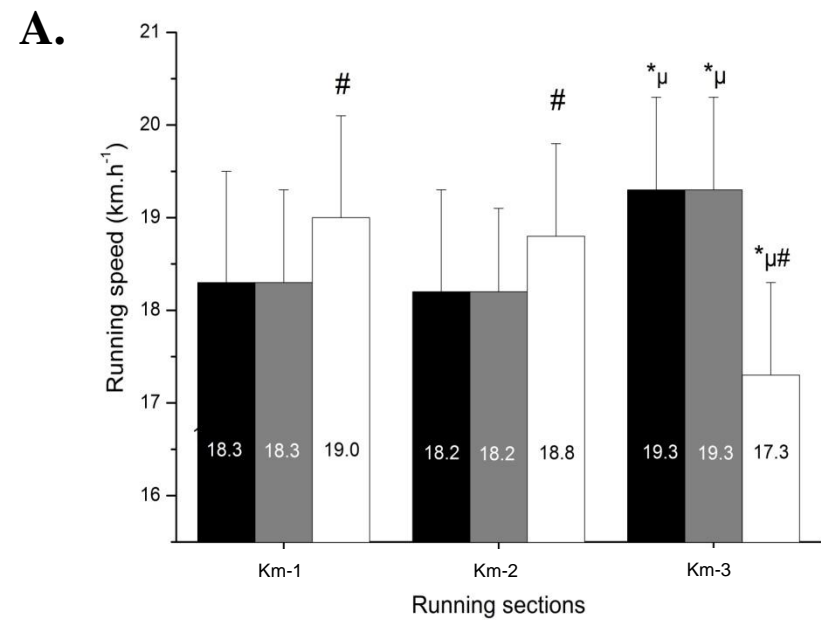
Figure 2

Figure 3

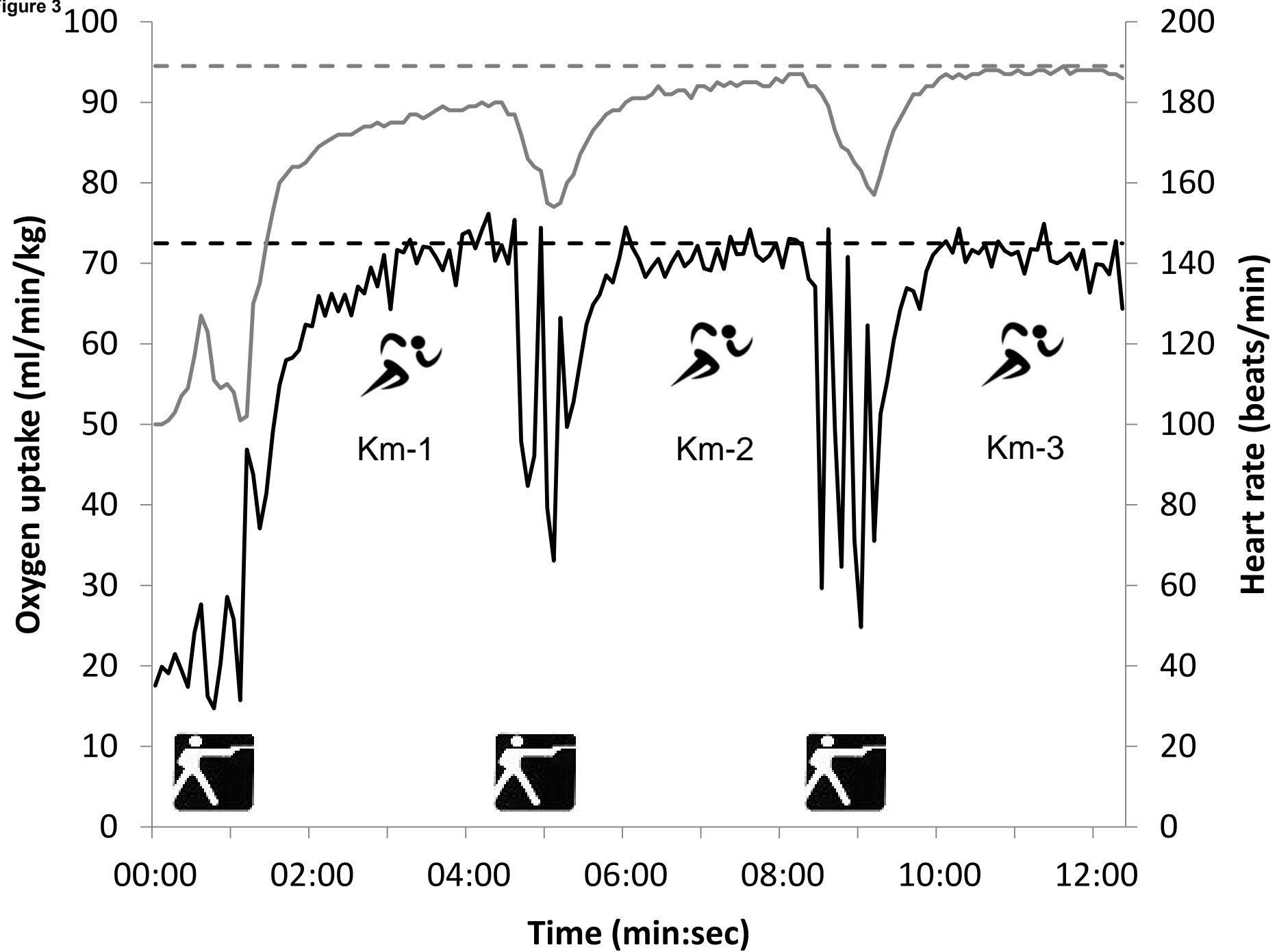


Table 1

	Men (<i>n</i> = 8)	Women (<i>n</i> = 1)
Age (years)	20 ± 3	20
Height (cm)	181 ± 4	174
Weight (kg)	74 ± 6	59
$\dot{V}O_{2\max}$ (mL.min ⁻¹ .kg ⁻¹)	74 ± 5	60
$\dot{V}_{E\max}$ (L.min ⁻¹)	170 ± 15	108
HR _{max} (beats.min ⁻¹)	197 ± 5	186
v_{\max} (km.h ⁻¹)	19,6 ± 1,0	17,0
$v \dot{V}O_{2\max}$ (km.h ⁻¹)	18,9 ± 0,5	17,0
v_{LT} (km.h ⁻¹)	16,6 ± 0,9	14,0
v_{LT} (% $\dot{V}O_{2\max}$)	93,0 ± 2,1	90,5

TABLE 1. Characteristics of the subjects participating in the present study (*n* = 9). 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; $v \dot{V}O_{2\max}$, velocity associated with $\dot{V}O_{2\max}$.

Table 2

	CEref	CE100%	CE105%
Overall combined event performance (s)	753 ± 30	770 ± 39	768 ± 27
Overall combined excluding the first shooting session (s)	705 ± 34	711 ± 33	715 ± 25
Total running time	581 ± 36	578 ± 34	588 ± 32
Mean running speed (km.h ⁻¹)	18.6 ± 1.1	18.7 ± 1.0	18.4 ± 1.0
Mean running speed (% vVO _{2max})	99.0 ± 4.3	99.0 ± 3.9	98.7 ± 3.3
Shooting accuracy (%)	75 ± 17	75 ± 20	73 ± 14
Shooting time (s)	80 ± 15	87 ± 26	84 ± 12
Mean delay per shooting attempt (s)	5.6 ± 0.6	5.8 ± 0.6	5.6 ± 0.5
Transition time (s)	29 ± 7	30 ± 5	32 ± 5

TABLE 2. Overall and isolated performances achieved during the three conditions. The shooting performances concern only the shooting sessions following the running legs (session 1 excluded). No significant difference was observed between the three conditions.

Table 3

Parameters	Oxygen uptake ($\dot{V}O_2$) (mL.min ⁻¹ .kg ⁻¹)			Expiratory flow (\dot{V}_E) (L.min ⁻¹)			Heart rate (beats.min ⁻¹)			Blood lactate ([La ⁻] _b) (mmol.L ⁻¹)
	Sections	Km-1	Km-2	Km-3	Km-1	Km-2	Km-3	Km-1	Km-2	Km-3
CE _{ref}	73.1 ± 3.7	73.1 ± 5.0	71.0 ± 5.8	153 ± 19	166 ± 16*	177 ± 25*	182 ± 4	189 ± 6*	195 ± 7*	13.6 ± 1.5
CE _{100%}	71.4 ± 4.1	72.4 ± 4.1	72.0 ± 5.2	152 ± 16	162 ± 15*	182 ± 22*	183 ± 5	189 ± 6*	194 ± 7*	13.7 ± 1.2
CE _{105%}	73.7 ± 5.3	72.5 ± 5.4	70.5 ± 6.1	162 ± 22 [#]	176 ± 24* [#]	176 ± 27	185 ± 8	189 ± 7*	190 ± 8 [#]	13.5 ± 1.5

*Significantly different from the previous section, $p < 0.05$.

Significantly different from CE_{ref} and CE_{100%}, $p < 0.05$.

TABLE 3. Group mean (\pm SD) values for oxygen uptake, expiratory flow, heart rate and blood lactate obtained during the running legs of the three combined events. All the measures were realised during the last 30s of each kilometre.