© by IAAF
28:3/4; 19-37, 2013

Maximal Lower Extremity Power Output Changes During a Decathlon

by Pascal Edouard, Jean-Benoît Mori and Pierre Samozino

ABSTRACT

This study sought to determine the changes in maximal leg power output over the course of a decathlon in order to better understand 1) the event's functional demands, 2) the muscular mechanical capabilities determining performance in the event, and 3) their relationships with injury risk factors. It was conducted under field conditions during the 2010 French National Combined Events Championships with six national-level athletes and 11 control participants as subjects. No differences in the values for squat jump and cycling sprint were found between tests at the beginning and end of each day (P>0.05), while significantly lower squat jump values at the start of the second day were reported for the control participants (P<0.05). The results suggest that a decathlon does not induce measurable alterations in lower extremity force, velocity or power output affecting performance and that the accumulation of fatigue (and/or neuromuscular fatigue, if any) does not play a major role in the injury risk associated with the event. The authors suggest that adapted wake-up and warm-up routines are necessary before morning events, particularly the 110m hurdles on the second day, and that other injury risk factors should be explored.

AUTHORS

Pascal Edouard, MD, PhD, is an assistant professor, works as physician in the Sports Medicine Unit in the Department of Clinical and Exercise Physiology at the University-Hospital of Saint-Etienne and is a researcher in the Laboratory of Exercise Physiology, University of Lyon. He is a member of the Medical Commission of the French Athletics Federation (Fédération Française d'Athlétisme).

Jean-Benoit Morin, PhD, is an assistant professor at the Department of Sport Sciences at the University of Saint-Etienne, and researcher at the Laboratory of Exercise Physiology, University of Lyon. He is a member of the French soccer federation research group, and collaborates with elite French sprinters, and high-level soccer and rugby teams.

Pierre Samozino, PhD, is an assistant professor in the Sport Science Department at the University of Savoy in Le Bourget du Lac, France.

Introduction

The decathlon is an athletics discipline during which participants run, jump, and throw through ten different events staged in a predetermined order over two consecutive days. Decathlon competitions consist of the 100m, long jump, shot put, high jump and 400m on the first day; and the 110m hurdles, discus, pole vault, javelin and 1500m on the second day[1-3]. In addition to technical skills in each of the disciplines, the decathlon demands a high level of muscular power, particularly in the legs. Overall success is dependent on the athlete being able to maintain his power output throughout the two days of repeated intermittent maximal efforts and the resulting neuromuscular fatigue, which is defined as "a reduction in the maximal force exerted by a muscle or a muscle group due to central and/or peripheral mechanisms"[4].

Decreases in lower extremity power output, measured through jump, sprint and/or maximal voluntary contraction tests, have been reported after repeated sprint or intermittent high-intensity exercises (e.g. soccer, handball, rugby, tennis…)[5-11]. Given this, we hypothesised that it would also be the case in decathlon, and that the amount of power decrease may be a key factor in decathlon performance. However, to our knowledge only two studies report information on physiological aspects during a decathlon (blood lactate accumulation[26] and cardiovascular demands[27]) and changes to the lower extremity power output have not been analysed. Since neuromuscular fatigue differs according to the type of muscle action, the muscular group involved and the exercises duration/intensity[12], it should be of interest to seek more specific knowledge regarding the development of fatigue and the change in lower extremity power output over the course of a decathlon.

In addition, a number of studies show that the injury rate in the decathlon is higher than in other athletics disciplines[2,3,13-19]. Incidences of time-loss injury in international-level decathlons have been shown to be from 122 to 200 per 1000 registered athletes compared to an overall time-loss injury risk around 45 to 70 per 1000 registered athletes[14-16]. The most common locations of decathlon-related injuries were in the lower extremities (~75%) and the majority of these injuries involved the musculo-tendinous system (e.g. hamstring strain, lower leg strain, Achilles tendinopathy and patellar tendinopathy)[13,17,20]. Thus, it should also be of interest to understand the power function of the lower extremities in the decathlon in order to improve injury prevention[13,14,19]. Moreover, it appears fundamental to follow a structured, step-by-step approach to obtain a precise description of any discipline and the main determinants of performance as a prerequisite for understanding injury causes and risk factors[21,22]. In this context, a better knowledge of the neuromuscular fatigue occurrence over the course of a decathlon, especially the change in lower extremity power output, should be of interest. Indeed, since neuromuscular fatigue could be considered as an injury risk factor[23-25], there may be a relationship between the potential decreased power output and the higher injury risk in the decathlon.

To summarise, evaluating the changes in lower extremity muscle power output over the course of a decathlon appears to be of interest for athletes, coaches and medical teams, to help them understand 1) the functional demands represented by the decathlon, 2) the muscular mechanical capabilities determining decathlon performance, and 3) their potential relationships with injury risk factors.

Although some studies report data on the dropout risk in decathlon and on the injury risk in decathlon, to our knowledge no data is available on the change in lower extremity power output induced by a decathlon. Therefore, we aimed to determine the change in lower extremity power output over the course of a decathlon, to relate it and its mechanical components to performances in the different events, and to discuss its role among injury risk factors. We were able to test this in a unique opportunity to perform evaluations in field conditions on athletes of various performance levels during a national championship decathlon.

Methods

Participants

Participants in this study were recruited from the athletes who competed in the 2010 French National Combined Events Championships in Saint-Etienne 26-27 June 2010 (for more information see: http://www.athle.fr/asp.net/main.html/html.aspx?htmlid=3607). Initially, eight male national-level athletes were included in this study. However, two athletes were not able to complete the entire event and the tests for the study because of injuries (a lower leg strain and a thigh laceration, respectively). Consequently, six male athletes (age (mean ± SD) 20.7 ± 5.1 years; body mass 75.3 ± 3.9kg; height 180.2 ± 4.5cm; body mass index (BMI) 23.2 ± 1.2kg.m^{-2}) were included as subjects (Table 1). The personal bests of participants at the time of the study ranged from 5505 to 7955 points, representing 81.5 ± 7.2% of the French national record (range from 74.7 to 92.8%). One subject was a world-class decathlete, who finished 2nd at the 2002 IAAF World Junior Championships, and 2nd in the heptathlon at the 2011 Indoor European Championships.

Eleven additional participants who were at the stadium as coaches, medical team or volunteers were included as controls. They were included if they were 1) free of health problems, 2) representative of athletes in terms of age, morphological and physical activity profile and 3) did not take part to the competition or other strenuous physical activity during the competition period. Their characteristics - age 25.5 ± 5.1 years; body mass 77.7 ± 10.4kg; height 180.6 ± 4.2cm; BMI 23.8 ± 2.4 kg.m^{-2} – did not differ significantly from the values of the competing athletes (Table 1).

All participants were physically active and had all practiced physical activities including sprints (e.g. athletics, decathlon, soccer, basketball) in the six months preceding the study. All were free of musculoskeletal pain or injury during the period of the study. All gave their written informed consent to participate in this study after being informed about the procedures approved by the French Athletic Federation Medical Commission's Ethical Committee and in agreement with the Declaration of Helsinki.

Field performances

For each competing athlete participating in the study, the total of points for the entire decathlon (decathlon performance), the best performance for each event (in points), the personal best after the competition, and the percentage of the French national record (at the time of the study according to category of age) were recorded.

Experimental procedures

The climatic conditions for the period of the study were: sunny without rain, wind from –1.7 to +3.0 m.s^{-1}, temperature from 17 to 30°C (from 0800 to 2000), humidity from 28.5 to 77.3%.

For each participant, the change in lower extremity power output was tested through squat jump (SJ) and cycling sprint (CS) measurements, which determined lower extremity power output as well as its force and velocity components (mechanical power being the product of force and velocity). Measurements were taken before the first event and after the last event on each of the two days of competition: at the beginning of Day 1 (PRE-D1), at the end of Day 1 (POST-D1), at the beginning of Day 2 (PRE-D2), and at the end of Day 2 (POST-D2). All measurements were performed in a room located 10m from the finish line, isolated from the audience and other athletes, with temperature and humidity that were similar to the outside conditions. An overview of the experiment is given in Figure 1.

Before each of the four measurement sessions, body mass was measured to the nearest 0.1kg using a standard scales with a numerical display. The body mass result before the measurement session was used to calculate maximal power output relative to body mass during the measurement session (e.g. body mass at PRE-D1 for measurements at PRE-D1). The PRE-D1 and PRE-D2 measurements were performed after an individual warm-up 10-15 minutes before the 100m and 110m hurdles, respectively; the POST-D1 and POST-D2 mea-

Table 1: Individual characteristics of the study participants (page 26 + 27)

	Age (years)	**Body mass (kg)**	**Height (cm)**	**Body Mass Index (kg.m^{-2})**
Athlete 1	16	69.3	175	22.6
Athlete 2	22	72.9	185	21.3
Athlete 3	17	74.3	175	24.3
Athlete 4	16	77.0	181	23.5
Athlete 5	27	78.6	185	23.0
Athlete 6	26	79.9	180	24.7
Athlete group (n=6)	20.7 ± 5.1	75.3 ± 3.9	180.2 ± 4.5	23.2 ± 1.2
Control participants (n=11)	25.5 ± 5.1	77.7 ± 10.4	180.6 ± 4.2	23.8 ± 2.4

[a] significant difference between before and after the Championships

* (last update June 25th, 2010)

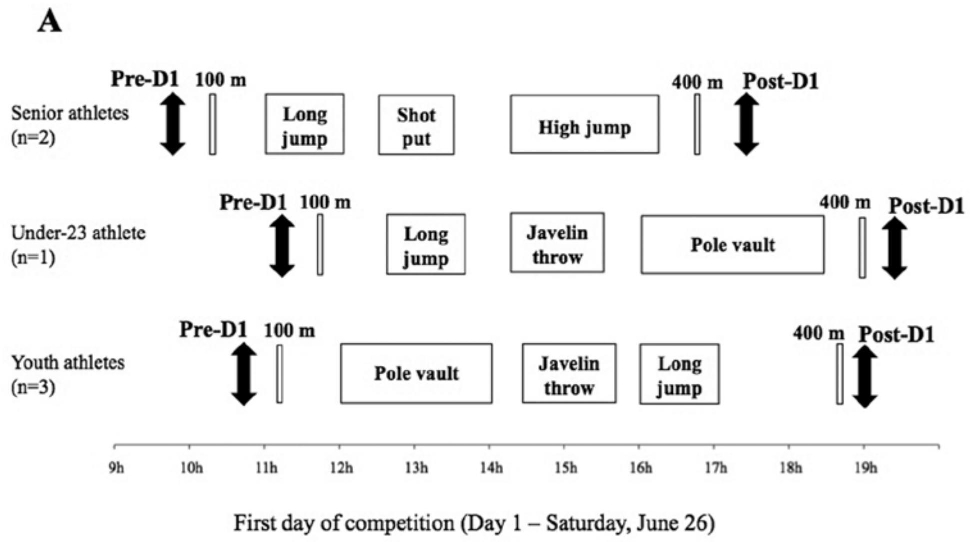
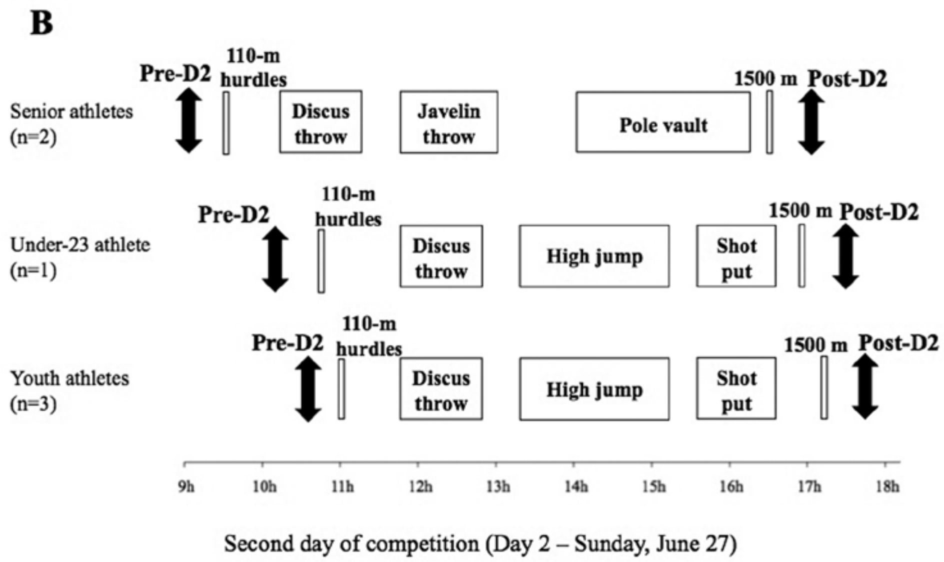


Figure 1: Overview of the experiment (For the six competing athletes, measurements were performed at the beginning and the end of the first (A) and second (B) days of competition: before Day 1 (PRE-D1), after Day 1 were performed at the same times.)

Personal Best before the Championships* (points)	(% of the National record)	Personal Best after the Championships (points)	(% of the National record)
6136	83.3	6169	83.7$
6243	75.2	6386	76.9$
5505	74.7	5872	79.7$
5683	77.1	5919	80.3$
7382	86.1	7382	86.1
7955	92.8	8110	94.6$
	81.5 ± 7.2		83.6 ± 6.3a

$ Athletes who improved their Personal Best during the Championships

PB = Personal Best



beginning and the end of the first (A) and second (B) days of competition: before Day 1 (PRE-D1), (POST-D1), before Day 2 (PRE-D2), after Day 2 (POST-D2). For the 11 control participants, measurements

surements were performed 20-25 minutes after the 400m and 1500m, respectively. The total energy and fluid intake were not recorded; athletes were allowed to eat and drink *ad libitum*.

The power output during a maximal SJ was also measured 12 times (between each event) for four athletes (age 17.8 ± 2.9 years; body mass 73.4 ± 3.2kg; height 179.0 ± 4.9cm; BMI 22.9 ± 1.3 kg.m^{-2}) and nine control participants (age 25.6 ± 5.4 years; body mass 74.8 ± 8.7kg; height 179.4 ± 3.5cm; BMI 23.2 ± 2.3 kg.m^{-2}). In these sub-groups, the athletes were significantly younger than control participants ($P<0.05$) but there were no other significant differences. The personal best, in decathlon of the four athletes at the time of the study (before the competition) ranged from 5505 to 6243 points, representing 77.6 ± 4.0% of the French national record (range from 74.7 to 83.3%). The measurements were taken 5-10 minutes after each event. The body mass measured at the beginning of the day was used to calculate maximal power output relative to body mass during the day (e.g. body mass at PRE-D1 for Day 1 and at PRE-D2 for Day 2). An overview of these additional measurements is given in Figure 2.

Squat jump

Force, velocity and power output of the lower extremity were measured during a SJ using a recently validated method[28]. Each participant performed two maximal SJs with the arms crossed on the torso, with one minute of

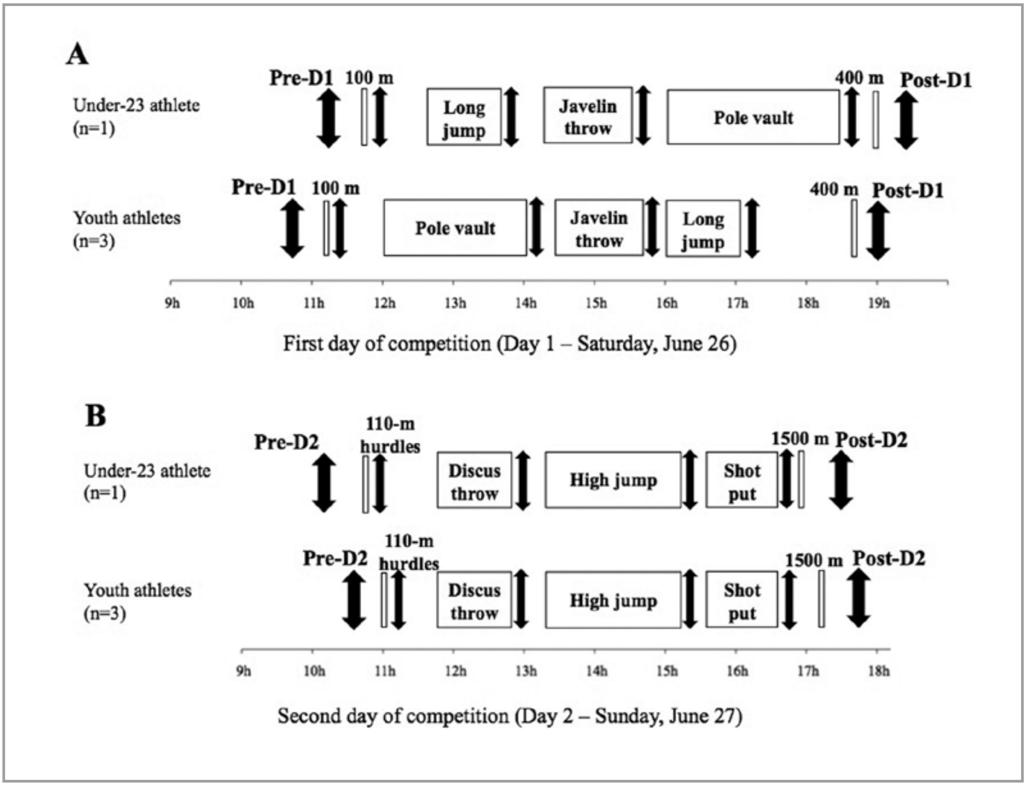


Figure 2: Overview of the additional measurements for the four competing athletes (Measurements including squat jump and cycling sprint (represented by a thick arrow) were performed at the beginning and the end of the first (A) and second (B) days of competition: before Day 1 (PRE-D1), after Day 1 (POST-D1), before Day 2 (PRE-D2), after Day 2 (POST-D2); measurements including only squat jump (represented by a thin arrow) were performed 5-10 minutes after each event. For the nine control participants, measurements were performed at the same times.)

rest between jumps. The vertical distance between the ground and the hip (great trochanter) of the right leg was measured in a 90°-knee angle crouch position set using a square (h_S). While standing, participants were asked to bend their legs and reach the starting height h_S (carefully checked with a ruler). After having maintained this crouch position for about 2 seconds, they were asked to apply force as fast as possible and to jump for maximum height. Countermovement was verbally forbidden and visually checked during each trial. At landing, participants were asked to touch down with the same leg position as when they took off, i.e. with extended leg and maximal foot plantar flexion. If all these requirements were not met, the trial was repeated.

Force (F_{SJ} in N.kg^{-1}), velocity (V_{SJ} in m.s^{-1}) and power (P_{SJ} in W.kg^{-1}) were calculated from three simple parameters: body mass (measured just before trials for PRE-D1, POST-D1, PRE-D2, and POST-D2, and at the beginning of the day for the 12 additional SJ measurements), jump height (*h,* highest values of the two trials) and vertical push-off distance (h_{po}) (for more details see SAMOZINO et al.[28]). Jump height (*h*) was measured using the Optojump light beam system (Microgate, Bolzano, Italy). Vertical push-off distance (h_{po}) was calculated as the difference between h_S and the extended lower extremity length with maximal foot plantar flexion (great trochanter to toe-tip distance).

Cycling sprint

Each participant performed one maximal CS on a standard friction-loaded cycle ergometer (Monark type 818 E, Stockholm, Sweden). The friction load applied to the inertial flywheel was 0.75 N.kg^{-1}. Instantaneous force and velocity were measured, respectively, by a strain gauge (Interface MFG type, Scottsdale, AZ, USA) and an optical encoder (Hengstler RIS IP50, 100 pts/turn, Aldingen, Germany) at 200Hz. Instantaneous power (*P* in W.kg^{-1}) was computed as the product of instantaneous total force and flywheel velocity: $P = (F_I + F_f).V;$ where F_f (N) is the friction force, F_I (N) the inertial force and *V* (m.s^{-1}) the flywheel linear velocity. Force, velocity and power were averaged by pedal downstroke. The linear F-V relationship ($FV\text{-}R_{cyc}$) was plotted from the force and velocity values for each participant, and was used to extrapolate the maximal force at zero velocity (F_{cyc}*-max*, N) and the maximal velocity at zero load (V_{cyc}*-max*, m.s^{-1}). The maximal power output (P_{cyc}*-max*, W.kg^{-1}) corresponded to the maximal value of power over one downstroke. For full details on these measurements, see MORIN et al.[29].

Data analysis and statistics

Descriptive statistics are presented as mean values ± SD. After normality checking by the Shapiro–Wilk test, and in case of normal distribution, for each value, two-way repeated measures ANOVAs were used to test the effects of time (PRE-D1, POST-D1, PRE-D2, and POST-D2) and group (athletes ***vs.*** control participants). Significant ANOVA results were followed by post hoc comparisons using Fischer's Protected Least Significant Difference (PLSD) post-hoc tests. For each value, the percentage of changes was also calculated for Day 1, for Day 2, between PRE-D1 and PRE-D2, and for the entire decathlon (equations are reported in Table 2). For the six athletes, correlations between field performances and experimental variables and their respective changes were performed using Pearson correlation coefficient. For the 12 additional SJ measurements, only descriptive analyses were performed. These analyses were performed with Statview® software (Version 5.0, SAS Institute Inc., Cary, NC). The significance level was set at $P < 0.05$.

Results

Note: All values showed a normal distribution.

Field performances

Of the six athletes tested, five beat their decathlon personal best during this competition with a significant mean increase in their decathlon personal best of 1.7 ± 4.1% ($P<0.05$) (Table 1).

Changes in body mass, squat jump and cycling sprint parameters.

No differences in body mass, SJ and CS-values at PRE-D1 were found between the ath-

Table 2: Changes in lower limb extensor muscle characteristics: force, velocity and power in squat jump and

Variables		**PRE-D1**		**POST-D1**		**PRE-D2**	
Body mass	A	75.3	± 3.9	74.2	± 3.7^{a,b}	75.4	± 4.0
	CP	77.7	± 10.4	77.3	± 10.2	78.0	± 10.2
Squat Jump values							
Power output P_{SJ} (W.kg^{-1})	A	29.2	± 3.0	28.5	± 2.8	27.6	± 2.8
	CP	26.1	± 4.7	25.8	± 4.2^{a,b}	24.6	± 3.7
Force F_{SJ} (N.kg^{-1})	A	20.6	± 1.3	20.3	± 1.1	20.0	± 1.3
	CP	19.4	± 1.9	19.3	± 1.8^{a,b}	18.8	± 1.6
Velocity V_{SJ} (m.s^{-1})	A	1.42	± 0.07	1.40	± 0.08	1.38	± 0.07
	CP	1.34	± 0.10	1.33	± 0.10^{a,b}	1.30	± 0.09
Cycling sprint values							
Maximal Power output P_{cyc}-max (W.kg^{-1})	A	13.9	± 1.3	14.0	± 1.0	13.7	± 1.3
	CP	13.1	± 0.9	13.2	± 0.9	12.7	± 0.9
Force F_{cyc}-max (N.kg^{-1})	A	1.99	± 0.26	1.97	± 0.27	1.97	± 0.24
	CP	1.92	± 0.20	2.05	± 0.12	1.97	± 0.15
Velocity V_{cyc}-max (m.s^{-1})	A	28.1	± 2.6	28.8	± 3.8	28.0	± 2.8
	CP	27.5	± 3.1	25.8	± 2.4	25.7	± 2.0
Force-Velocity relationship FV_{cyc}-R_{cyc}	A	-0.54	± 0.11	-0.52	± 0.13	-0.54	± 0.12
	CP	-0.56	± 0.16	-0.62	± 0.14	-0.60	± 0.12

[a] *Significant difference with PRE-D1;*

[b] *Significant difference with PRE-D2.*

The percentage of changes were calculated using the following equation: % of changes during D1 =
*% of changes between PRE-D1 and PRE-D2 = (PRE-D2 – PRE-D1)/PRE-D1*100; and % of change during*
range 0.343-0.957; all P<0.001).

letes and control participants, confirming that control participants were representative of the athletes tested.

For the athletes, body mass decreased significantly during both Day 1 and the Day 2. No change in body mass was reported for the control subjects (Table 2).

For athletes, no differences in SJ and CS values were observed between the testing times (Table 2 and Figure 3).

For the control participants, SJ force, velocity and maximal power output PRE-D2 was significantly lower than PRE-D1, POST-D1 and POST-D2. No differences in CS values were reported between testing times (Table 2 and Figure 3).

in cycling sprint and in body mass during a decathlon competition for athletes (A) and control participants (CP)

POST-D2		% of changes during D1		% of changes during D2		% of changes between PRE-D1 and PRE-D2		% of changes during decathlon	
74.4	± 3.4^{a,b}	-1.54	± 0.70	-1.20	± 1.34	0.04	± 1.29	-1.16	± 1.37
80.1	± 8.4	-0.54	± 0.80	-0.44	± 0.96	0.30	± 0.63	-0.15	± 0.88
28.8	± 3.2	-2.24	± 5.54	4.16	± 6.49	-5.28	± 6.36	-1.46	± 7.11
25.5	± 4.2^{b}	-0.61	± 5.07	3.31	± 4.48	-5.11	± 5.33	-1.98	± 6.62
20.4	± 1.1	-1.20	± 2.84	2.01	± 3.16	-2.75	± 3.32	-0.83	± 3.64
19.1	± 1.8^{b}	-0.36	± 2.45	1.62	± 2.20	-2.63	± 2.71	-1.05	± 3.30
1.41	± 0.09	-1.11	± 2.78	2.02	± 3.19	-2.69	± 3.24	-0.75	± 3.60
1.32	± 0.10^{b}	-0.31	± 2.62	1.62	± 2.21	-2.62	± 2.75	-1.04	± 3.42
13.5	± 1.0	1.49	± 5.47	-0.75	± 5.28	-1.42	± 3.01	-2.18	± 5.77
12.8	± 0.9	0.89	± 6.92	1.08	± 5.26	-2.98	± 7.58	-2.15	± 6.09
1.94	± 0.24	-0.27	± 12.03	-0.83	± 9.12	-0.73	± 9.86	-2.19	± 5.00
1.95	± 0.09	7.47	± 11.67	-0.75	± 7.60	3.25	± 8.27	2.54	± 12.30
28.0	± 2.4	3.00	± 13.83	1.04	± 13.29	0.04	± 9.47	0.15	± 6.57
26.2	± 1.8	-4.99	± 13.04	2.26	± 7.59	-5.55	± 9.82	-3.24	± 13.53
-0.52	± 0.10	-2.11	± 24.48	-0.62	± 21.84	0.82	± 20.28	-3.02	± 9.70
-0.58	± 0.06	15.97	± 28.83	-2.39	± 14.96	11.32	± 18.62	9.57	± 30.46

*(POST-D1 – PRE-D1)/PRE-D1*100; % of changes during D2 = (POST-D2 – PRE-D2)/PRE-D2*100;*
*decathlon = (POST-D2 – PRE-D1)/PRE-D1*100. All linear F-V regressions were significant (mean r^2 of 0.854,*

For the 12 additional measurements in the four athletes and nine control participants, the changes in power output in maximal squat jump during the decathlon competition are presented in Figure 4. We can observe that in three of the athletes there is a trend to decrease in performance during Day 2, especially at the beginning of the day.

Correlations between field performances and experimental parameters

We observed a significant correlation between velocity in squat jump PRE-D1 and performance in the decathlon (r=0.864; *P*<0.05) (Figure 5), and between the percentage of changes in cycling sprint force during the decathlon (between PRE-D1 and POST-D2) and performance in decathlon (r=0.859; *P*<0.05) (Figure 6). All correlations analyses are reported in Table 3.

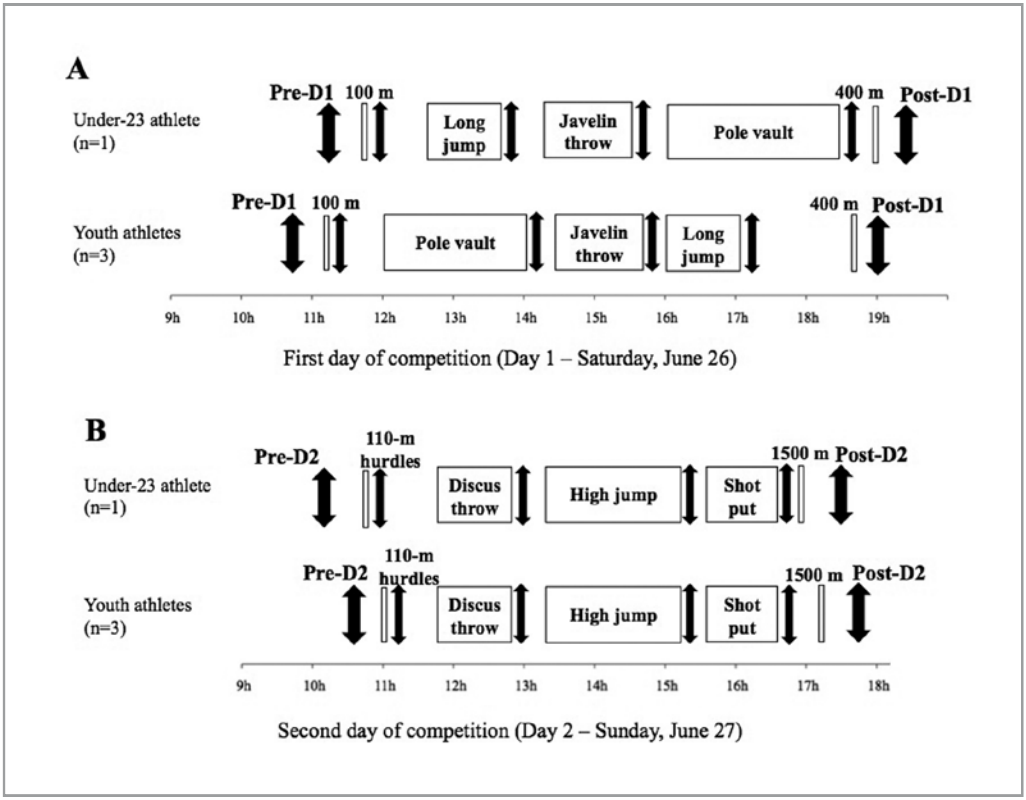


Figure 2: Overview of the additional measurements for the four competing athletes (Measurements including squat jump and cycling sprint (represented by a thick arrow) were performed at the beginning and the end of the first (A) and second (B) days of competition: before Day 1 (PRE-D1), after Day 1 (POST-D1), before Day 2 (PRE-D2), after Day 2 (POST-D2); measurements including only squat jump (represented by a thin arrow) were performed 5-10 minutes after each event. For the nine control participants, measurements were performed at the same times.)

Discussion

The major strengths of this study were 1) it was the first to evaluate lower extremity muscle capabilities over the course of a decathlon with the aim of improving performance knowledge and giving potential insight into injury prevention, 2) the measurements were taken under field conditions during a national championships involving national- and international-level athletes, and 3) there were representative control participants to rule out the potentially confounding effects of the circadian rhythm.

No change in lower extremity power output was induced by a decathlon competition

The main finding was that competition in a two-day decathlon is not associated with measurable changes in lower extremity extensor muscle power output, suggesting there was no functional effect of neuromuscular fatigue and no fatigue accumulation induced by the event. Our hypothesis that competing in a decathlon would lead to significant alterations in muscle force, velocity or power output due to repeated maximal efforts over the course of the two days of competition was not supported by the results, suggesting that there is no associated neuromuscular fatigue.

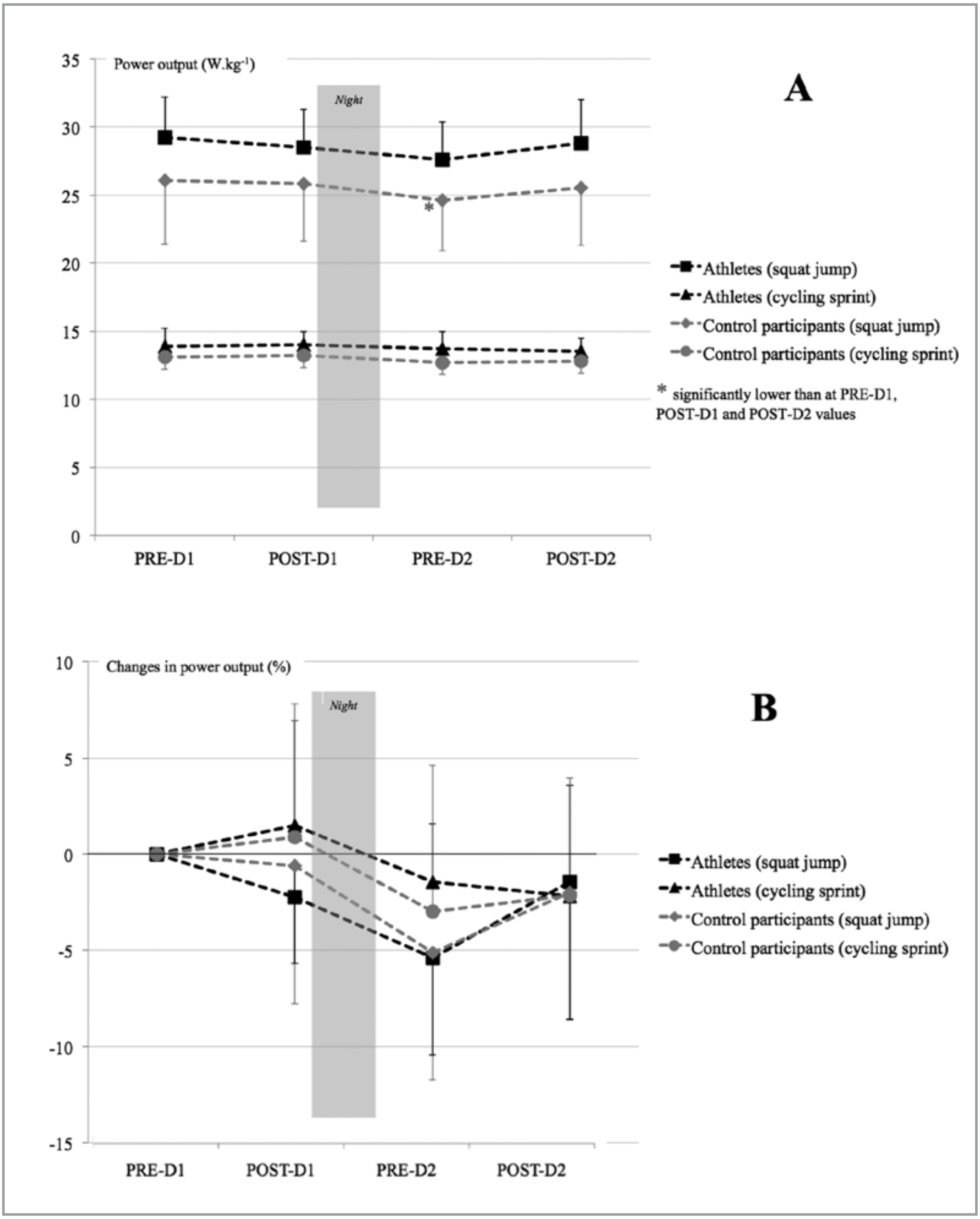


Figure 3: Changes in power output (expressed in W.kg^{-1} (A) and in relative change from PRE-D1 (B)) during squat jump and cycling sprint in athletes (n=6) and control participants (n=11) over the course of a decathlon competition

Table 3: Pearson correlation coefficients between squat jump or cycling sprint values (rows) and field perfor-

Variables	Decathlon performance (total of points)	100m
Squat Jump values		
Power output PSJ (W.kg^{-1}) at POST-D2	0.672	0.627
Percentage of changes in Power output PSJ (W.kg^{-1}) during D2	0.788	0.551
Percentage of changes in Force FSJ (N.kg^{-1}) during D2	0.805	0.580
Velocity VSJ (m.s^{-1}) at PRE-D1	**0.864**	**0.843**
Percentage of changes in Velocity VSJ (m.s^{-1}) during D2	0.768	0.524
Cycling sprint values		
Maximal power output Pcyc (W.kg^{-1}) at PRE-D1	-0.127	-0.343
Maximal power output Pcyc (W.kg^{-1}) at POST-D2	-0.184	-0.449
Force Fcyc (N.kg^{-1}) at PRE-D1	-0.501	-0.685
Percentage of changes in Force Fcyc (N.kg^{-1}) during D1	0.611	0.252
Percentage of changes in Force Fcyc (N.kg^{-1}) between POST-D2 and PRE-D1	**0.859**	0.753
Force-Velocity relationship at PRE-D1	0.473	0.625
Percentage of changes in Force-Velocity relationship between POST-D2 and PRE-D1	**0.830**	0.764

We report non-significant mechanical performance change after a decathlon compared with significant mechanical performance decrease of 3-33% after intermittent high-intensity exercises (team- and racket-sports)[5-11]. In soccer, handball and rugby, reduced neural input and muscular capabilities were observed after matches, and recovery to baseline levels took 1-3 days[7-11]. These results suggested that the physiological demands and related-fatigue are different between decathlon and team sports. Indeed, in team- and racket-sports, exercises are short-duration sprints/efforts (<10 seconds) interspersed with brief recoveries (<60 seconds) over an extended period of time (1-4 hours)[5,10]. In the decathlon, the athletes have to perform very-high intensity short-duration efforts (<3-6 seconds for jumps and throws, and <15 seconds for runs, except for the 400m and 1500m), with long rest periods (at least 30 minutes of rest between each event during which they have to manage recovery and their warm-up for the next event), over two days (around 18 hours on the stadium)[26,27]. In the decathlon, most of the energy used is made available by the adenosine triphosphate (ATP) and creatine *mances (columns). (Significant correlation (**P**<0.05) when r>0.811 (in bold).)*

Long jump	Shot put	High jump	400m	110m hurdles	Discus throw	Pole vault	Javelin throw	1500m
0.815	0.239	0.754	0.550	-0.045	0.096	0.672	0.531	0.681
0.788	0.005	**0.815**	**0.913**	0.403	0.077	**0.880**	**0.814**	0.602
0.815	0.010	**0.834**	**0.912**	0.412	0.081	**0.892**	**0.830**	0.612
0.922	0.380	**0.873**	0.631	0.330	0.337	**0.820**	0.748	0.721
0.768	-0.016	0.799	**0.906**	0.392	0.059	**0.865**	0.797	0.590
0.203	-0.730	0.282	0.113	-0.744	**-0.858**	0.084	-0.252	0.351
-0.003	-0.458	0.081	0.190	**-0.816**	-0.653	0.008	-0.298	0.258
-0.357	-0.396	-0.207	-0.286	**-0.984**	-0.615	-0.367	-0.733	0.140
0.412	0.160	0.584	**0.819**	0.316	0.224	0.702	0.545	0.582
0.617	**0.844**	0.658	0.692	0.452	0.790	0.757	0.700	0.680
0.457	0.080	0.323	0.281	**0.890**	0.323	0.402	0.701	-0.073
0.768	0.523	0.806	0.566	0.365	0.493	0.764	0.640	0.762

phosphate (CP) systems for jumps and throws, and completed by anaerobic glycolysis for sprints[5,26]. DURAND et al.[27] reported that heart rate was close to maximal during each sprint/jump event or attempt, and recovered quickly at levels close to inactivity. The long rest period between each event and attempt allows full recovery and re-synthesis of ATP[5]. Thus, the decathlon can not be compared to a repeated-sprint exercises, but rather to an intermittent-sprint exercise (or intermittent-maximal exercise)[5].

Moreover, the slow recovery processes (1 to 3 days) reported in team-sport and racket games have been attributed to structural changes (force-transmitting structures or force-producing)[7-11]. Therefore, RONGLAN et al.[7] suggest the introduction of specific high-intensity activities like sprinting, jumping and eccentric exercises in training in order to prevent lower extremity structural changes and neuromuscular fatigue. Since these specific types of training are already performed by decathletes, it could explain the absence of decrease in lower extremity power output after a decathlon, and

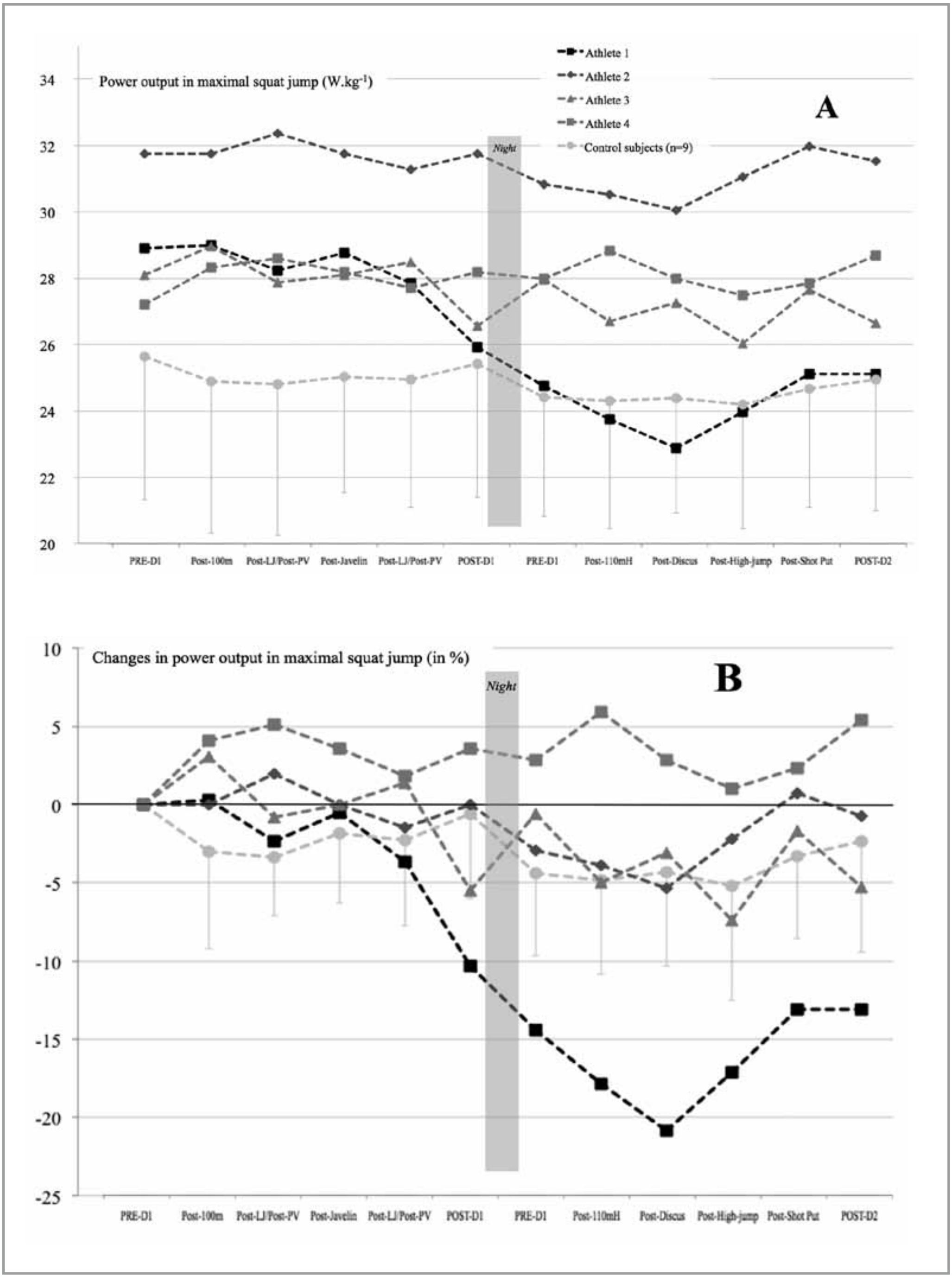


Figure 4: Changes in squat jump maximal power output in W.kg^{-1} (A) and in % of the initial value (B) in competing athletes (n=4) and control participants (n=9) over the course of a decathlon competition (LJ: long jump; PV: pole vault)

the absence of functional consequence of the neuromuscular fatigue after a decathlon.

Limitations

Some possible limitations of this study have to be discussed. First, the testing modalities we used (i.e. squat jump and cycle sprint) mainly involve concentric actions in comparison to the stretch-shortening cycle actions performed in decathlon events. The measurements were to be made in field conditions during a national championship competition and we therefore chose evaluations that did not interfere with the competition and performances. These tests are quickly performed and easy to plan in field conditions, and seem to have no consequence on performance. Importantly, they have been used to explore power output changes in team-sport and racket games in previous field-condition studies[7,8]. Furthermore, quantifying muscle power output through SJ and sprint cycling has been shown reliable (CV<7%) and sensitive to change[28,30].

Second, the resultant change in power output we observed might result from both fatigue and potentiation, the relative importance of which is difficult to distinguish. However, we thought it relevant to determine and analyse the changes in net power output since it is what an athlete can really produce in field conditions.

Third, it is difficult to know if the athletes were really trying to do their best at each testing session. However, we can report that each participant freely accepted to participate in this study after being informed about the procedures and their consequences on their competition.

Fourth, the number of athletes included could be considered small for highlighting differences and extrapolating results. However, this number was similar to that of the two previous decathlon field studies[26,27], and only slightly lower than previous field-condition studies on neuromuscular fatigue in other sports[7,8]. Moreover, our aim to test elite athletes during a national Championships made inclusion of additional participants difficult.

Finally, the timing of post-effort assessment could be considered as too long (10-25 minutes), but it was similar to or lower than that of previous studies[8,9,11] that reported neuromuscular fatigue (or the functional consequences of neuromuscular fatigue) 24 to 72 hours after intermittent high-intensity exercises[7-9].

Practical implications to improve decathlon performance

An insignificant decrease in squat jump power output in the morning of the second day (PRE-D2) was reported for the participating athletes and a significant lower power output was reported for the control participants. This result may be due to circadian rhythm[31,32]. Thus, we suggest to athletes and coaches that an adapted wake-up and warm-up is necessary and important when events take place in the morning, especially before the 110m hurdles, in order to improve performance, and to prevent injury. A high level of vigilance is required to perform well in this very technical discipline, in which the slightest error can lead to a fall (indeed, a high injury risk has been reported in hurdles during international championships[14]). Moreover, further studies are required to record the wake-up and warm-up procedures athletes perform and their relationships with performance and/or injury.

The correlations between field performances and experimental measurements revealed interesting results to better define/understand the physical capabilities allowing decathlon performance. The velocity component of the maximal squat jump power output was significantly correlated with the overall performance in decathlon, and was also significantly correlated with performance in the following specific events: 100m, long jump, high jump and pole vault; suggesting that it is a relevant capability to perform well in decathlon. This is in agreement with recent findings on 100m performance, which reported that a “velocity-oriented” force-velocity profile is one of the most relevant determinants of the 100m performance[33]. Thus, as recently proposed[34], training programmes should be monitored through regular neuromuscular assessments in order to optimise the force-ve-

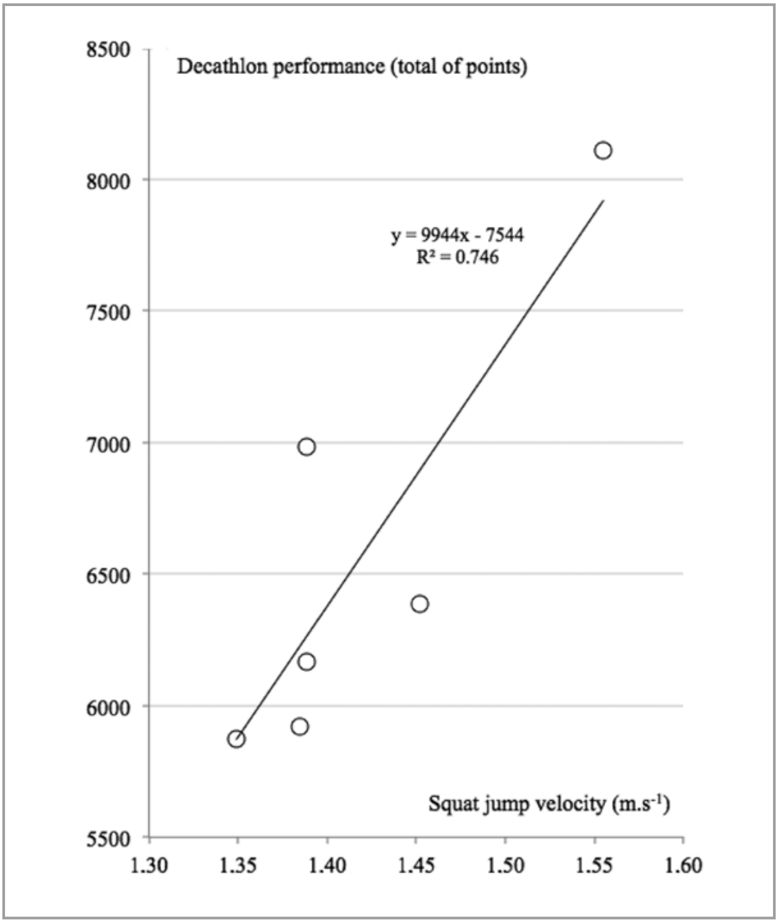


Figure 5: Significant correlation between velocity in squat jump at PRE-D1 and performance in decathlon (r=0.864; P<0.05)

locity profile. Indeed, there is a significant contribution of the mechanical force-velocity imbalance to explain jumping performance variability, suggesting the interest of normalising the force-velocity profile[35].

A lower decrease in the force component of cycling sprint power output was significantly correlated with a higher total performance in decathlon, suggesting that the decrease in force component of cycling sprint power output can affect the ability to complete a decathlon. In this context, it could be relevant for athletes to improve their capability to maintain a high level of force throughout the repeated events.

Injury risk factors and injury-prevention strategies in decathlon

Since we reported no decrease in lower extremity power output induced by a decathlon, we can reasonably assume that the accumulation of fatigue (and/or neuromuscular fatigue, if any) does not play a major role in injury risk in decathlon. Thus, other aspects should be considered as risk factors, such as internal and external factors and/or changes in postural control, technical ability, sensorimotor control, over a decathlon[22]. The higher injury risk reported in decathlon may be due to the sum of the injury risks of the 10 events. Future studies should help better understand the mechanisms of in-

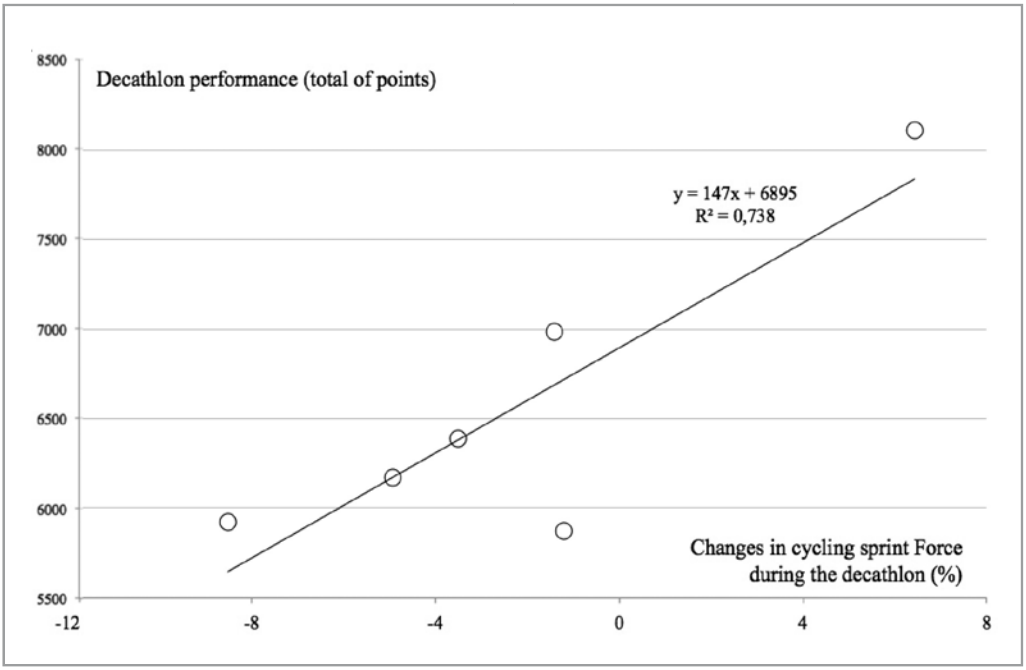


Figure 6: Significant correlation between the relative changes in cycling sprint force during the decathlon (between PRE-D1 and POST-D2) and overall decathlon performance (r=0.859; P<0.05)

jury occurring during a decathlon by the use of athletes' interview, clinical studies, or video analysis, and to improve the knowledge of the physiological and biomechanical constraints induced by the decathlon[22].

The decathlon leads to a small decrease in body mass (~1%), similar to that reported after soccer[8] or tennis[10] matches. This suggested little dehydration, although energy and fluid intake have not been recorded. Since dehydration is a frequent time-loss illness[14] and can cause physical and mental performance decrement[36], athletes should be advised to hydrate regularly[14,36].

Conclusions

No significant changes in lower extremity muscle power output were reported over the course of a decathlon, suggesting no substantial neuromuscular fatigue was induced by the two days of competition. Our study could be considered as a pilot study, and future studies should be done to confirm these preliminary results by 1) including more athletes, 2) increasing the number of measurements (such as agonist/antagonist muscle balance, more direct assessment of the neuromuscular fatigue and its central and peripheral features, biological parameters) and 3) exploring the influence of experience, training and level of practice on neuromuscular fatigue, with longer follow-up (0 to 72 hours after decathlon).

Acknowledgements

The authors greatly appreciated the cooperation of the participating athletes and their coaches during the study. They would like to thank the Coquelicot 42 (The Athletics Club of Saint-Etienne, France) and the Association of the Cotation Table Knight for their logistic support to this project.

Please send all correspondence to:
Dr Pascal Edouard
Pascal.Edouard42@gmail.com

REFERENCES

1. ZARNOWSKI, F. (2001). The nature of decathlon. In: Horn GM, Gardner C, editors. ***A basic guide to Decathlon***. Torrance, CA: Griffin Publishing Group: 27-37.

2. EDOUARD, P. (2011). Frequency of dropouts in decathlon: An epidemiological retrospective study. ***Sci Sports,*** 26 97-100.

3. EDOUARD, P.; MORIN, J.-B.; CELLI, F.; CELLI, Y. & EDOUARD, J.-L. (2009). Dropout in international combined events competitions. ***New Studies in Athletics,*** 24 (4): 63-68.

4. ENOKA, R.M. & STUART, D.G. (1992). Neurobiology of muscle fatigue. ***J Appl Physiol,*** 72 (5): 1631-1648.

5. GIRARD, O.; MENDEZ-VILLANUEVA, A. & BISHOP, D. (2011). Repeated-sprint ability - part I: factors contributing to fatigue. ***Sports Med,*** 41 (8): 673-694.

6. MORIN, J.B.; SAMOZINO, P.; EDOUARD, P. & TOMAZIN, K. (2011). Effect of fatigue on force production and force application technique during repeated sprints. ***J Biomech,*** 44 (15): 2719-2723.

7. RONGLAN, L.T.; RAASTAD, T. & BORGESEN, A. (2006). Neuromuscular fatigue and recovery in elite female handball players. ***Scand J Med Sci Sports,*** 16 (4): 267-273.

8. ANDERSSON, H.; RAASTAD, T.; NILSSON, J.; PAULSEN, G.; GARTHE, I. & KADI, F. (2008). Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery. ***Med Sci Sports Exerc,*** 40 (2): 372-380.

9. RAMPININI, E.; BOSIO, A.; FERRARESI, I.; PETRUOLO, A.; MORELLI, A. & SASSI, A. (2011). Match-related fatigue in soccer players. ***Med Sci Sports Exerc,*** 43 (11): 2161-2170.

10. GIRARD, O.; LATTIER, G.; MAFFIULETTI, N.A.; MICALLEF, J.P. & MILLET, G.P. (2008). Neuromuscular fatigue during a prolonged intermittent exercise: Application to tennis. ***J Electromyogr Kinesiol,*** 18 (6): 1038-1046.

11. THORLUND, J.B.; MICHALSIK, L.B.; MADSEN, K. & AAGAARD, P. (2008). Acute fatigue-induced changes in muscle mechanical properties and neuromuscular activity in elite handball players following a handball match. ***Scand J Med Sci Sports,*** 18 (4): 462-472.

12. MILLET, G.Y. & LEPERS, R. (2004). Alterations of neuromuscular function after prolonged running, cycling and skiing exercises. ***Sports Med,*** 34 (2): 105-116.

13. EDOUARD, P.; SAMOZINO, P.; ESCUDIER, G.; BALDINI, A. & MORIN, J.B. (2012). Injuries in Youth and National Combined Events Championships. ***Int J Sports Med,*** 33 (10): 824-828.

14. ALONSO, J.M.; EDOUARD, P.; FISCHETTO, G.; ADAMS, B.; DEPIESSE, F. & MOUNTJOY, M. (2012). Determination of future prevention strategies in elite track and field: analysis of Daegu 2011 IAAF Championships injuries and illnesses surveillance. ***Br J Sports Med,*** 46 (7): 505-514.

15. ALONSO, J.M.; TSCHOLL, P.M.; ENGEBRETSEN, L.; MOUNTJOY, M.; DVORAK, J. & JUNGE, A. (2010). Occurrence of injuries and illnesses during the 2009 IAAF World Athletics Championships. ***Br J Sports Med,*** 44 (15): 1100-1105.

16. EDOUARD, P.; DEPIESSE, F.; BRANCO, P. & ALONSO, J.M. (2013 Dec 9. [Epub ahead of print]). Analyses of Helsinki 2012 European Athletics Championships injury and illness surveillance to discuss elite athletes risk factors. ***Clin J Sport Med***.

17. EDOUARD, P.; KERSPERN, A.; PRUVOST, J. & MORIN, J.B. (2012). Four-year injury survey in heptathlon and decathlon athletes. ***Sci Sports,*** 27 (6): 345-350.

18. EDOUARD, P. & ALONSO, J.M. (2013). Epidemiology of track and field injuries. ***New Studies in Athletics,*** 28 (1/2): 85-92.

19. EDOUARD, P.; MOREL, N.; SERRA, J.-M.; PRUVOST, J.; OULLION, R. & DEPIESSE, F. (2011). [Prevention of musculoskeletal injuries in track and field. Review of epidemiological data]. ***Sci Sports,*** 26 307-315.

20. EDOUARD, P.; PRUVOST, J.; EDOUARD, J.L. & MORIN, J.B. (2010). Causes of dropouts in decathlon. A pilot study. ***Phys Ther Sport,*** 11 (4): 133-135.

21. VAN MECHELEN, W.; HLOBIL, H. & KEMPER, H.C. (1992). Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. ***Sports Med,*** 14 (2): 82-99.

22. BAHR, R. & KROSSHAUG, T. (2005). Understanding injury mechanisms: a key component of preventing injuries in sport. ***Br J Sports Med,*** 39 (6): 324-329.

23. WOODS, C.; HAWKINS, R.D.; MALTBY, S.; HULSE, M.; THOMAS, A. & HODSON, A. (2004). The Football Association Medical Research Programme: an audit of injuries in professional football--analysis of hamstring injuries. ***Br J Sports Med,*** 38 (1): 36-41.

24. SMALL, K.; MCNAUGHTON, L.; GREIG, M. & LOVELL, R. (2010). The effects of multidirectional soccer-specific fatigue on markers of hamstring injury risk. ***J Sci Med Sport,*** 13 (1): 120-125.

25. MORAN, K.A. & MARSHALL, B.M. (2006). Effect of fatigue on tibial impact accelerations and knee kinematics in drop jumps. ***Med Sci Sports Exerc,*** 38 (10): 1836-1842.

26. BEAULIEU, P.; OTTOZ, H.; GRANGE, C.; THOMAS, J. & BENSCH, C. (1995). Blood lactate levels of decathletes during competition. ***Br J Sports Med,*** 29 (2): 80-84.

27. DURAND, S. & BEAUNE, B. (2006). [Heart rate variation throughout the decathlon]. ***Sci Sports,*** 21 (1): 32-35.

28. SAMOZINO, P.; MORIN, J.B.; HINTZY, F. & BELLI, A. (2008). A simple method for measuring force, velocity and power output during squat jump. ***J Biomech,*** 41 (14): 2940-2945.

29. MORIN, J.B. & BELLI, A. (2004). A simple method for measurement of maximal downstroke power on friction-loaded cycle ergometer. ***J Biomech,*** 37 (1): 141-145.

30. HOPKINS, W.G.; SCHABORT, E.J. & HAWLEY, J.A. (2001). Reliability of power in physical performance tests. ***Sports Med,*** 31 (3): 211-234.

31. RACINAIS, S.; CONNES, P.; BISHOP, D.; BLONC, S. & HUE, O. (2005). Morning versus evening power output and repeated-sprint ability. ***Chronobiol Int,*** 22 (6): 1029-1039.

32. REILLY, T. & WATERHOUSE, J. (2009). Sports performance: is there evidence that the body clock plays a role? ***Eur J Appl Physiol,*** 106 (3): 321-332.

33. MORIN, J.B.; BOURDIN, M.; EDOUARD, P.; PEYROT, N.; SAMOZINO, P. & LACOUR, J.R. (2012). Mechanical determinants of 100-m sprint running performance. ***Eur J Appl Physiol,*** 112 (11): 3921-3930.

34. SAMOZINO, P.; REJC, E.; DI PRAMPERO, P.; BELLI, A. & MORIN, J.B. (2012). Optimal Force–Velocity Profile in Ballistic Movements—Altius: Citius or Fortius? ***Med Sci Sports Exerc,*** 44 (2): 313-322.

35. SAMOZINO, P.; EDOUARD, P.; SANGNIER, S.; BRUGHELLI, M.; GIMENEZ, P. & MORIN, J.B. (2013). Force-Velocity Profile: Imbalance Determination and Effect on Lower Limb Ballistic Performance. E-publication ahead of print, in Int J Sports Med.

36. MAUGHAN, R.J. & SHIRREFFS, S.M. (2010). Development of hydration strategies to optimize performance for athletes in high-intensity sports and in sports with repeated intense efforts. Scand J Med Sci Sports, 20 Suppl 2 59-69.