Journal of Science and Medicine in Sport 27 (2024) 302–306

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Brief report

Is the risk of muscle injuries higher in the finals than in previous rounds of the 100 m, 200 m and 400 m sprints of international athletics championships?

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ARTICLE INFO

Article history:
Received 11 July 2023
Received in revised form 5 December 2023
Accepted 19 February 2024
Available online 22 February 2024

Keywords:
Sports injury prevention
Performance
Epidemiology
Track and field
Top-level athletes
Muscle injury risk

ABSTRACT

Objectives: To compare incidence rates of lower limb muscle injuries (LLMIs) and hamstring muscle injuries (HMIs) in 100 m, 200 m and 400 m sprints disciplines between finals, semi-finals and heats of international athletics championships.
Design: Prospective total population study.
Methods: We analysed in-competition LLMIs and HMIs of female and male athletes during eight championships between 2009 and 2022.
Results: LLMI and HMI incidence rates in 100 m finals were significantly higher than in heats and semi-finals for female and male athletes. HMI incidence rates were significantly higher in 200 m finals than heats and semi-finals for male athletes.
Conclusions: LLMI and HMI risk was higher in finals compared to previous rounds during international athletics championships.

Practical implications

- The risk of LLMI and of HMI was higher in 100 m finals compared to previous rounds during international athletics championships for female and male athletes.
- The risk of HMI was higher in 200 m finals compared to previous rounds during international athletics championships for male athletes.
- Several physical and psychological factors can explain this higher muscle injury risk in finals.
- We suggest better preparing athletes for multiple rounds during international athletics championships by improving i) resistance to fatigue to better manage the multiple rounds, and ii) stress management to cope with finals.

1. Introduction

During international athletics championships, in-competition lower limb muscle injuries (LLMIs) were the most frequent injuries in disciplines involving running (*i.e.*, sprints, hurdles, jumps, combined events, middle distance runs, long distance runs, and marathons), represented 36 % of all injuries.[1] This proportion was even higher in sprints (*i.e.*, 60 m (indoor), 100 m, 200 m, 400 m, 4 × 100 m relay and 4 × 400 m relay[2]): 41 % in female and 67 % in male athletes.[1] The location of LLMIs varied across disciplines according to their required running velocities, *e.g.* the proportion of hamstring muscle injuries (HMIs) increased

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https://doi.org/10.1016/j.jsams.2024.02.007

with discipline-required running velocity.[1] HMIs were most prevalent in sprints, with 59 % resp. 52 % of all LLMIs and 12.7 resp. 25.1 injuries per 1000 registered athletes in female and male athletes.[1] Thus, LLMIs, and in particular HMIs, represent a crucial issue for athletes and their entourage, strengthening the need to better understand the causes of their occurrence to improve prevention strategies. Several factors can play a role in the occurrence of injuries during international athletics championships, such as previous injury,[3] male sex,[4] higher age,[5,6] or type of event/discipline.[7] An aspect that has not been analysed yet is the stage of the competition. Considering the physical and mental stress to perform at best to qualify for the next round, the risk of LLMI might be higher in heats or semi-finals than in finals. Or, on the contrary, finals may have a higher risk for these injuries, because *i)* velocities could be faster, *ii)* athletes might be fatigued from previous rounds, and/or *iii)* on the psychological stress could have been increased. Therefore, we aimed to compare the incidence rates of LLMIs and HMIs between finals, semi-finals and heats of sprint disciplines during international athletics championships.

2. Methods

We retrospectively analysed the in-competition LLMIs and HMIs of athletes participating in 100 m, 200 m and 400 m sprints prospectively collected during eight international athletics championships: World Outdoor Championships 2009,[8] 2011,[9] 2013[10]; and European Outdoor Championships 2012,[5] 2014, 2016, 2018 and 2022. We only included outdoor championships, because distances, conditions and gyratory angle for distance higher than 60 m, are different during indoor championships (60 m instead of 100 m, no 200 m, and 400 m is performed with two rounds of a 200 m track and athletes being in the same corridor for the second round). We excluded 1) disciplines and events with only one round (*e.g.*, combined events, marathon, race walking) because a comparison between finals and previous rounds is not possible, 2) relays, events of more than 400 m, as well as throws and jumps, because there could be some passing strategies in each round. There was no patient or public involvement. The study protocol was reviewed and approved by the Saint-Etienne University Hospital Ethics Committee (Institutional Review Board: IORG0007394; IRBN742020/CHUSTE). All injury reports in the database were anonymous.

All data were prospectively collected using the same study design, injury definition and data collection procedures, previously described in detail.[1,6,7] Injuries were defined as "all musculoskeletal injuries (traumatic and overuse) and concussion newly incurred during competition or training regardless of the consequences with respect to the athlete's absence from competition or training".[2,7] Diagnoses were based on clinical examination and/or medical imaging by the national medical teams and/or by local organising committee physicians; no specific diagnostic criteria were sent out in advance.[6] The injuries were included in the analysis if they met the following criteria: *i)* occurred in 100 m, 200 m and 400 m sprints, *ii)* occurred during competitions or warmup for competition (training injuries were excluded), *iii)* affected the hip, groin, thigh, knee, lower leg, ankle or foot, and *iv)* were classified as "strain/muscle rupture/tear" or "muscle cramps or spasm".[1] All in-competition LLMIs and all HMIs were analysed.

We extracted the number of athletes' starts in each round (*i.e.*, heats, semi-finals and finals) and the athletes' performance (*i.e.*, time) from the results list of World Athletics (https://worldathletics.org/competition/calendar-results). We compared the performances *i)* between finals *vs.* heats and *ii)* between finals *vs.* semi-finals, for each sex and event (*i.e.*, 100 m, 200 m and 400 m sprint) using Student's *t*-test. We calculated incidence rates[11] (*i.e.* number of injuries per 1000 starts (with 95 % confidence intervals)), separately for each sex, event (*i.e.*, 100 m, 200 m and 400 m sprint) and round (*i.e.*, heats, semi-finals and finals). We compared the incidence rates *i)* between finals *vs.* heats, *ii)* between finals *vs.* semi-finals, and *iii)* between semi-finals *vs.* heats, for each sex and event using relative risk (with 95 % confidence intervals (95 % CI)). Significance was accepted at $p < 0.05$.

3. Results

A total of 1642 starts for female and 1840 starts for male athletes in all rounds (*i.e.*, heats, semi-finals and finals) of 100 m, 200 m and 400 m were registered during the eight championships (Table 1). The average performances were significantly better in the finals than in the semi-finals or heats, for each sex and event (Table 1 and Fig. 1).

On average, 90.6 % of the national medical teams, covering 84.6 % of the registered athletes, participated in the injury surveillance project and returned 93.7 % of the report forms. No athlete refused the use of his/her data for scientific research.

A total of 150 in-competition injuries in 100 m, 200 m and 400 m sprints were recorded, of which 91 were classified as LLMI (60.1 %) and 45 as HMI (30 % of in-competition injuries, or 49.5 % of LLMI). The numbers of injuries and the incidence rates per sex and event are presented in Table 1. The LLMI incidence rates in 100 m finals were significantly higher than heats and semi-finals for female (relative risk (RR) = 9.71 (95% CI: 2.38 to 39.65) resp. RR = 6.88 (95% CI: 1.37 to 34.56)) and male athletes (RR = 5.10 (95% CI: 2.55 to 10.17) resp. RR = 6.90 (95% CI: 2.53 to 18.83)) (Table 2 and Fig. 1). The HMI incidence rates were significantly higher *i)* in 100 m finals than heats for female athletes (RR = 11.66 (95 % CI: 1.07 to 126.68)), *ii)* in 100 m and 200 m finals than heats and semi-finals for male athletes (RR = 5.16 (95 % CI: 1.69 to 15.76) resp. RR = 3.59 (95 % CI: 1.00 to 12.97) and (RR = 4.40 (95 % CI: 1.11 to 15.95) resp. RR = 5.50 (95 % CI: 1.03 to 29.31)), and *iii)* in 200 m semi-finals than heats for female athletes (RR = 5.50 (95 % CI: 1.03 to 29.31)) (Table 2 and Fig. 1).

4. Discussion

The main findings of the present study were that during international athletics outdoor championships, the incidence rates of 1) LLMI in 100 m finals were higher than heats or semi-finals for female and male athletes, 2) HMI in 100 m finals were higher than heats or semi-finals for female and male athletes, 3) HMI in 200 m finals were higher than heats or semi-finals for male athletes, and 4) LLMI and HMI were similar in semi-finals and heats (except for 200 m female athletes).

A potential explanation of the higher LLMI and HMI risk in finals compared to other rounds is that athletes are more fatigued (including neuromuscular and mental fatigue) in finals than in heats and semi-finals. Although the duration of the sprint is very short (*i.e.*, from 10 s. to 25 s. according to the event), the total duration of the effort during competition including the warmup is longer. There could be also a cumulative fatigue effect of the rounds during the competition that can create great physical and mental stress for the athlete. It has been suggested based on empirical evidence that sessions with maximal sprints, as during international championships, require at least 48 h of recovery because they are highly demanding for the central nervous system.[12] However, in the context of international athletics championships, there is often not 48 h between two rounds, and it is often one round per days over three days, and for 100 m often the semi-finals around 2 h before the finals. This supports the hypothesis that fatigue contributes to the higher rate of LLMI and HMI in finals than heats. In addition, mental fatigue, stress and pressure may also play a role as risk factors.[13,14] It can be assumed that the pressure and stress during the finals are higher than in previous rounds. Finally, from a biomechanical perspective, the higher LLMI and HMI risk in finals could be due to the higher running velocity required/achieved in finals than in previous rounds. In the present study, we showed that running velocities were significantly faster in finals than in the previous rounds (Table 1 and Fig. 1). And, it has been reported that higher running velocities were associated with higher LLMI and HMI risk.[1] So, the LLMI and HMI risk could be linked to the athlete's running velocity: higher running velocity associated with higher muscle injury risk. In addition, finals being the

Table 1
Number of starts, mean performances (in seconds), number and incidence of in-competition lower limb muscles injuries (LLMIs) and hamstring muscle injuries (HMIs) according to sex and events (*i.e.*, 100 m, 200 m and 400 m) during eight international athletics outdoor championships 2009 to 2022.

	Number of starts	Performance in seconds (means (SD))	Number of LLMIs (n (%))	Incidence rate of LLMIs (95% CI)	Number of HMIs (n (%))	Incidence rate of HMIs (95% CI)
Female athletes						
100 m						
Heats	373	11.86 (1.78)	3 (30.0)	8.0 (−1.0 to 17.1)	1 (33.3)	2.7 (−2.6 to 7.9)
Semi-finals	176	11.33 (0.21)	2 (20.0)	11.4 (−4.3 to 27.0)	0 (0.0)	0.0 (0.0 to 0.0)
Finals	64	11.23 (0.65)	5 (50.0)	78.1 (12.4 to 143.9)	2 (66.7)	31.3 (−11.4 to 73.9)
200 m						
Heats	275	23.54 (0.80)	4 (28.6)	14.5 (0.4 to 28.7)	1 (11.1)	3.6 (−3.5 to 10.8)
Semi-finals	192	23.16 (0.50)	8 (57.1)	41.7 (13.4 to 69.9)	6 (66.7)	31.3 (6.6 to 55.9)
Finals	64	22.78 (0.41)	2 (14.3)	31.3 (−11.4 to 73.9)	2 (22.2)	31.3 (−11.4 to 73.9)
400 m						
Heats	258	53.06 (1.92)	0 (0.0)	0.0 (0.0 to 0.0)	0 (0.0)	0.0 (0.0 to 0.0)
Semi-finals	176	51.82 (1.02)	0 (0.0)	0.0 (0.0 to 0.0)	0 (0.0)	0.0 (0.0 to 0.0)
Finals	64	51.06 (1.06)	1 (100.0)	15.6 (−14.8 to 46.0)	0 (0.0)	0.0 (0.0 to 0.0)
Male athletes						
100 m						
Heats	462	10.56 (0.49)	17 (50.0)	36.8 (19.6 to 54.0)	7 (43.8)	15.2 (4.0 to 26.3)
Semi-finals	184	10.25 (0.23)	5 (14.7)	27.2 (3.7 to 50.7)	4 (25.0)	21.7 (0.7 to 42.8)
Finals	64	10.11 (0.20)	12 (35.3)	187.5 (91.9 to 283.1)	5 (31.3)	78.1 (12.4 to 143.9)
200 m						
Heats	352	20.99 (0.51)	11 (61.1)	31.3 (13.1 to 49.4)	5 (45.5)	14.2 (1.8 to 26.6)
Semi-finals	176	20.66 (0.42)	3 (16.7)	17.0 (−2.1 to 36.2)	2 (18.2)	11.4 (−4.3 to 27.0)
Finals	64	20.31 (0.43)	4 (22.2)	62.5 (3.2 to 121.8)	4 (36.4)	62.5 (3.2 to 121.8)
400 m						
Heats	282	46.43 (1.31)	10 (71.4)	35.5 (13.9 to 57.0)	4 (66.7)	14.2 (0.4 to 28.0)
Semi-finals	192	45.77 (0.65)	0 (0.0)	0.0 (0.0 to 0.0)	0 (0.0)	0.0 (0.0 to 0.0)
Finals	64	45.31 (0.55)	4 (28.6)	62.5 (3.2 to 121.8)	2 (33.3)	31.3 (−11.4 to 73.9)

LLMIs, lower limb muscle injuries; HMIs, hamstring muscle injuries; n, numbers; SD, standard deviation.
The performances were significantly better in finals than in semi-finals or heats for both sexes and all events.

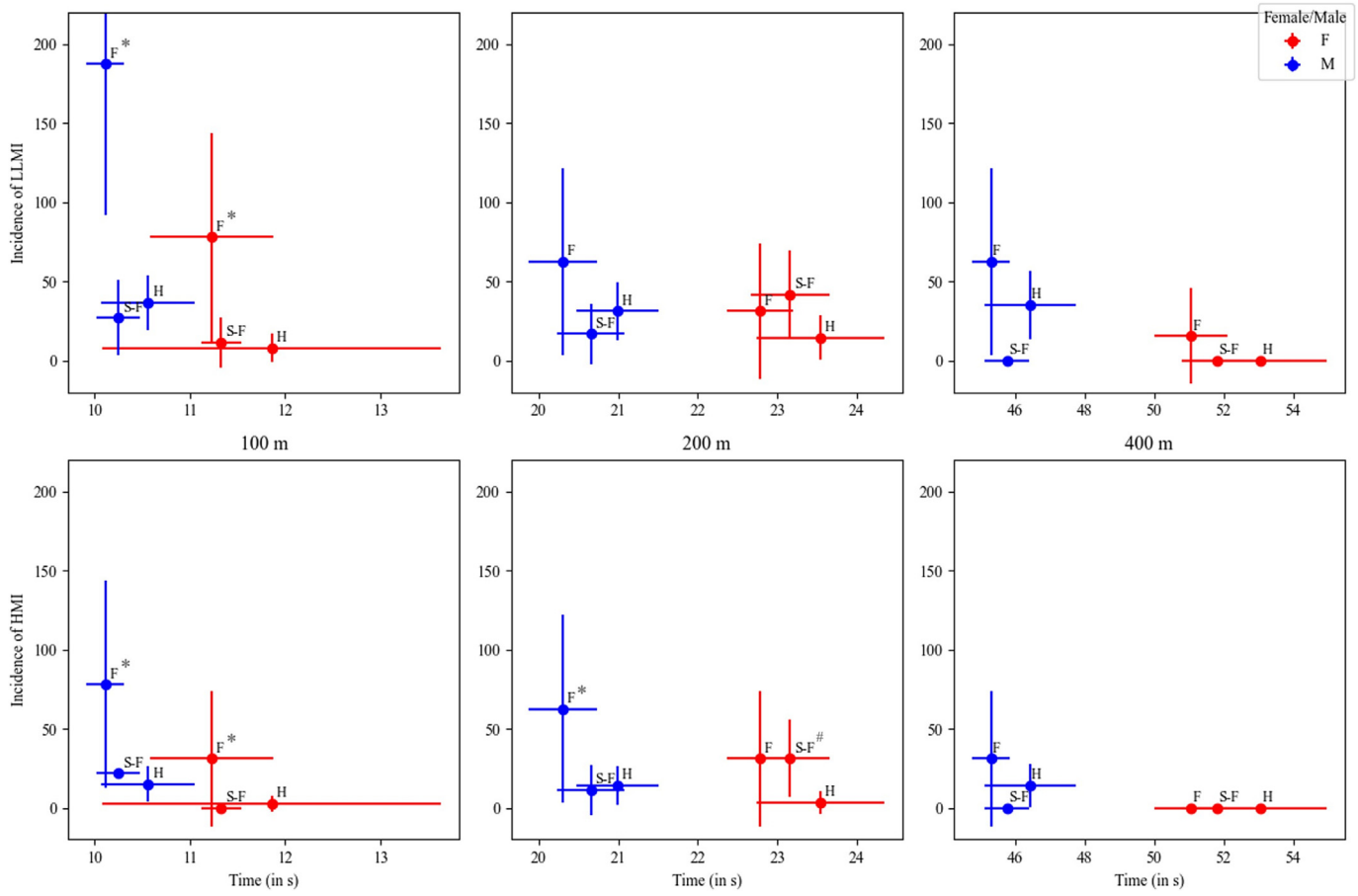

Fig. 1. Number of in-competition lower limb muscles injuries (LLMIs) and hamstring muscle injuries (HMIs) per 1000 starts (*i.e.*, incidence rates) with the 95 % confidence intervals according to performance (average time in seconds with Standard Deviation) for female (red) and male (blue) athletes during heats (H), semi-finals (S-F) and finals (F) of the 100 m, 200 m and 400 m sprints of the eight international athletics outdoor championships from 2009 to 2022. *: incidence rates in finals significantly higher than in semi-finals and heats; # incidence rates in semi-finals significantly higher than in heats.

Table 2
Comparisons of incidence rates (*i.e.*, number of injuries per 1000 starts) during eight international athletics outdoor championships 2009 to 2022 *i)* between finals *vs.* heats, *ii)* between finals *vs.* semi-finals, *iii)* between semi-finals *vs.* heats, for each sex and event, using relative risk (with 95 % confidence intervals due to the two comparisons). Significant differences are highlighted in bold.

	100 m	200 m	400 m
Relative risk of LLMI incidence (±95% CI)			
Female athletes			
Finals *vs.* heats	**9.71 (2.38 to 39.65)**	2.15 (0.40 to 11.48)	–
Finals *vs.* semi-finals	**6.88 (1.37 to 34.56)**	0.75 (0.16 to 3.44)	–
Semi-finals *vs.* heats	1.41 (0.24 to 8.38)	2.86 (0.87 to 9.38)	–
Male athletes			
Finals *vs.* heats	**5.10 (2.55 to 10.17)**	2.00 (0.66 to 6.09)	1.76 (0.57 to 5.44)
Finals *vs.* semi-finals	**6.90 (2.53 to 18.83)**	3.67 (0.84 to 15.94)	–
Semi-finals *vs.* heats	0.74 (0.28 to 1.97)	0.55 (0.15 to 1.93)	–
Relative risk of HMI incidence (±95% CI)			
Female athletes			
Finals *vs.* heats	**11.66 (1.07 to 126.68)**	8.59 (0.79 to 93.32)	–
Finals *vs.* semi-finals	–	1.00 (0.21 to 4.83)	–
Semi-finals *vs.* heats	–	**8.59 (1.04 to 70.81)**	–
Male athletes			
Finals *vs.* heats	**5.16 (1.69 to 15.76)**	**4.40 (1.11 to 15.95)**	2.20 (0.41 to 11.77)
Finals *vs.* semi-finals	**3.59 (1.00 to 12.97)**	**5.50 (1.03 to 29.31)**	–
Semi-finals *vs.* heats	1.43 (0.43 to 4.84)	0.80 (0.16 to 4.08)	–

LLMIs, lower limb muscle injuries; HMIs, hamstring muscle injuries; 97.5% CI: 97.5 % confidence intervals.

most competitive race, running velocity is expected to be highest as well, leading to increased hamstring muscle activation as reported in a recent meta-analysis.[15] Such increased in running velocity can also lead to modification in running technic (*e.g.*, lose their body position (such as pelvis tilt), disrupt the muscle coordination ('muscular music'),[16] increase co-contractions), and thus, could lead to exaggerated constraints on muscles.

The present study has a few limitations in addition to those previously discussed regarding injury data collection in the context of international athletics championships.[1,4,6,7] Although 91 LLMIs were included in the present study, the number of injuries in specific events was low. However, almost all results were in the same direction, even those that did not reach statistical significance. Further, it is possible that some athletes preferred to not report injuries in heats or semi-finals to the medical teams for health problems in order to stay focused on the performance goal and/or to avoid any contraindications to participate in the next round. Finally, our analyses were not adjusted to other confounding factors (*e.g.*, age, previous injuries) that can influence the occurrence of muscle injury.

5. Conclusions

Our present study showed that the risk of sustaining an LLMI or an HMI in sprint events is higher in finals than in previous rounds of international athletics championships. As practical implications, we suggest better preparing athletes for multiple rounds during international athletics championships by improving i) resistance to fatigue to better manage the multiple rounds, and ii) stress management to cope with finals.

CRediT authorship contribution statement

PE and KH conceived the study; PE, PED and PB participated to injury data collection; PE, PED and LN discussed and performed data analyses; PE drafted the manuscript; and all co-authors discussed the analysis, contributed substantially to interpreting the results, provided important revisions, and approved the manuscript. All authors understand that they are accountable for all aspects of the work and ensure the accuracy or integrity of this manuscript.

Funding information

No specific funding was received for the present study. The present study was conducted in the context of the FULGUR project funded by the French Research Agency in the perspective of the Paris 2024 Olympic and Paralympic Games in collaboration with French Federations of Athletics, Rugby and Ice Sports, Universities of Nantes, Côte d'Azur, Savoie Mont Blanc, Jean Monnet Saint-Etienne, Saclay, the Mines Saint-Etienne, the CEA and the CNRS. The University Jean Monnet Saint-Etienne and the French Institute of Sport (INSEP) are partners of the French-speaking network ReFORM, recognised as a Research Centre for the Prevention of Injury and Illness and the Protection of Athletes by the Olympic Committee (IOC). As a member of the IOC Medical Research Network, ReFORM has received funding from the IOC to establish long-term research programme on the prevention of injuries and illnesses in sport for the protection of athlete health.

Confirmation of ethical compliance

The study protocol was reviewed and approved by the Saint-Etienne University Hospital Ethics Committee (Institutional Review Board: IORG0007394; IRBN742020/CHUSTE).

Data availability

Data are available upon reasonable request. Requests for data sharing from appropriate researchers and entities will be considered on a case-by-case basis. Interested parties should contact the corresponding author Pascal Edouard (pascal.edouard@univ-st-etienne.fr).

Declaration of interest statement

None declared. PE is an Associate Editor for the British Journal of Sports Medicine. KH is an Editor for the German Journal of Sports Medicine. PE and KH are Associate Editors for the BMJ Open Sports and Exercise Medicine.

Acknowledgements

The authors appreciate the cooperation they received from the medical staff of national teams and the physicians attached to competition organising committees who collect the data for this project.

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