

Sprint-related hamstring injuries in professional football occur closer to individual maximal running speed: a matched video and tracking case–control study

Aaron Miralles-Iborra

Sports Research Centre (Department of Sport Sciences), Universidad Miguel Hernández

Tomás Urbán

t.urban@umh.es

Sports Research Centre (Department of Sport Sciences), Universidad Miguel Hernández

Juan Del Coso

Sport Sciences Research Centre, Rey Juan Carlos University

Roberto López-Del Campo

Department of Competitions and Mediacoach, LaLiga

Ricardo Resta

Department of Competitions and Mediacoach, LaLiga

Víctor Moreno-Pérez

Sports Research Centre (Department of Sport Sciences), Universidad Miguel Hernández

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Abstract

Background

To determine whether sprint-related hamstring muscle injuries in professional football occur at higher absolute and player-normalised speeds than matched non-injury sprints.

Methods

Forty sprint-related hamstring muscle injury events from 34 male professional football players were retrospectively analysed in a case-control study combining video analysis with Mediacoach® optical tracking data to describe injury context and quantify sprint characteristics. Each injury sprint was matched with two eligible non-injury sprints performed by the same player and official match, yielding 40 matched sets and 120 sprint actions. The primary normalised-speed exposure was calculated relative to the player's highest speed recorded earlier in the same season, excluding injury match. Speed normalised to the peak speed recorded in the injury match was examined secondarily. Conditional logistic regression accounted for the matched design.

Results

Injury sprints reached higher absolute peak speed than controls (27.2 ± 3.7 vs 26.0 ± 3.0 km · h⁻¹; 95% CI 0.08 to 2.30; $p = 0.036$) and occurred closer to the player's maximal pre-injury season speed ($85.0 \pm 12.0\%$ vs $81.1 \pm 10.1\%$; 95% CI 0.42 to 7.36; $p = 0.029$). Each 10-percentage point increase in season-normalised speed was associated with higher odds that the sampled sprint was injury-related (OR = 2.01, 95% CI 1.09 to 3.71). A similar association was observed in the secondary analysis using peak match speed as the reference (OR = 1.91, 95% CI 1.07 to 3.38). Most injuries were non-contact (95%), occurred without ball possession (72%) and involved open kinetic-chain actions (75%).

Conclusions

Sprints during which hamstring injuries occurred were performed at modestly higher absolute and pre-injury season-normalised speeds than selected non-injury sprints completed by the same player in the same match.

INTRODUCTION

Hamstring muscle injuries are the most frequent muscle injuries in professional football with 16.3–19.0% of total injuries [1–3]. Further, the incidence of hamstring muscle injuries in professional football increases over the time at a rate of 3.9–6.7% per year during match and training respectively [2, 3]. Previous reports showed that hamstring muscle injuries cause an important time loss, with an average resulting in approximately 17 days of absence although some players may need several weeks to return to play [4]. In addition, hamstring muscle injuries have a high recurrence rate, with approximately 18–20% of cases resulting in reinjury [5]. These consequences impose a substantial burden on professional football, negatively affecting team performance and generating significant long-term financial costs due to player unavailability [2, 6]. Thus, preventing hamstring muscle injury in football might have a critical importance for overall football performance and the well-being of professional football players.

To implement preventive strategies during football practice, the identification of observable mechanisms associated with hamstring muscle injury is paramount.

It is well recognised that most severe football hamstring muscle injuries occur with a non-contact mechanism during sprinting or high-speed running [7–9]. A recent study reported that most hamstring injuries in elite football players occurred when players ran > 25 km · h⁻¹ and above 80 % of their maximal speed [9]. During high-speed running, the hamstring muscle-tendon unit is exposed to substantial eccentric demands during late swing, when the hamstrings decelerate knee extension and contribute to hip stability before ground contact [10]. The biceps femoris long head is considered particularly vulnerable during these actions because it experiences substantial mechanical strain and force absorption and transmission during sprinting [7, 11].

Video analysis has improved our understanding of injury mechanisms in football by allowing the contextual, situational and biomechanical features preceding injury to be described in detail [12]. Previous video-analysis studies [7, 13–15] have shown that hamstring muscle injuries commonly occur during high-speed running, often without direct contact, and may be influenced by match context, playing situation and running mechanics [7, 13–15]. However, most existing studies have focused on describing injury events alone [7, 13–15]. Consequently, although previous studies have established sprinting as a common injury-inciting action, it remains unclear whether the sprint in which injury occurs is mechanically or kinematically distinguishable from other sprint actions that the same player successfully completes during match play.

Absolute speed thresholds are commonly used in football to monitor sprint exposure [16–18]. However, a given absolute speed may represent a different physiological and mechanical demand depending on the player's maximal speed capacity [19]. For example, running at $28 \text{ km} \cdot \text{h}^{-1}$ may represent a near-maximal action for one player but a moderate sprint for another. Therefore, player-specific normalised speed may provide a more meaningful estimate of the mechanical demand imposed on the hamstring muscle–tendon unit than absolute speed alone [20]. To the authors' knowledge, there is a lack of studies describing whether sprint-related hamstring muscle injuries occur during actions performed at higher absolute and normalised running speeds compared with matched non-injury sprints. Matched same-player and same-match non-injury sprints were therefore used as controls. The player's highest speed recorded before the injury during the same season, excluding the injury match, was selected as the primary reference for normalisation because it was independent of the injury and control sprints within each matched set. The peak speed recorded during the injury match was also examined as a secondary reference.

Therefore, the primary objective of this study was to determine whether sprint-related hamstring muscle injuries in professional football occur at higher pre-injury season-normalised speed than matched non-injury sprints. Secondary objectives were to compare absolute sprint speed and other kinematic characteristics, examine speed normalised to peak match speed as a secondary analysis, explore predefined normalised-speed thresholds, and describe the contextual video-analysis characteristics of sprint-related hamstring muscle injuries. Unlike previous video-analysis studies that primarily described injury events, this matched design allowed us to examine differences between an injury sprint and other selected sprint actions performed by the same player. We hypothesised that injury sprints would occur at a higher proportion of the player's maximal pre-injury season speed than matched non-injury sprints. We further hypothesised that injury sprints would show higher absolute maximal and mean running speeds. Threshold-based analyses were considered exploratory.

METHODS

Study design

This was a retrospective matched video and tracking case–control study. The injury definition, diagnosis confirmation and inclusion of subsequent events were prespecified in accordance with the STROBE-SIIS recommendations for observational studies [21]. Hamstring muscle injuries were reported by the medical staff of each team and match footage and tracking data were obtained from *LaLiga*. Sprint-related hamstring muscle injury events were considered case sprints. Each injury sprint was matched with two eligible non-injury sprints performed by the same player during the same official match. Eligible controls satisfied the same minimum speed and duration criteria as injury sprints. Among eligible control actions, the 2 sprints with the highest absolute speeds and most comparable durations were selected before calculating the normalised-speed variables. Control selection was performed independently of the season-normalised-speed value used as the primary exposure (Fig. 1). This design was chosen to reduce between-player variability in maximal speed capacity, anthropometrics, playing role and individual sprint profile. An a priori design-based sample size calculation was conducted for the primary conditional logistic regression analysis. Assuming one injury sprint matched with two non-injury control sprints, a two-sided alpha level of 0.05, 80% statistical power, and an odds ratio of 1.75 per one-standard-deviation increase in the primary continuous exposure, 38 complete matched sets were required.

All data were anonymised in accordance with the Declaration of Helsinki to ensure confidentiality of players and teams. The study protocol was approved by the Research Ethics Committee of Miguel Hernández University (code: CID.VMP.240322). *LaLiga* authorised the use of match performance data for research purposes, and the study does not contain information that identifies players.

Participants and injury selection

The final sample comprised 40 sprint-related acute hamstring muscle injuries of 4 teams competing during official matches in the top division of the Spanish football league (*LaLiga*) were included in the final analysis from five seasons (2020–2021 to 2024–2025), each matched with two non-injury control sprints, resulting in 40 matched sets and 120 sprint observations. These injuries occurred in 34 different outfield players (age: 28.1 ± 4.8 years, body mass: 76.0 ± 6.5 kg, height: 181.7 ± 5.4 cm). In the final sample, there were 17 defenders, 10 midfielders, and 13 forwards. All injuries were diagnosed and recorded by the clubs' medical staff using the classification system developed by the International Olympic Committee Consensus Group [22]. Players could contribute more than one injury event when the subsequent event was considered a distinct index injury rather than an early recurrence. Subsequent events were eligible when they occurred in the contralateral limb, involved a different hamstring muscle or anatomical location. Recurrent injuries, defined as injuries involving the same muscle and anatomical location [22], were excluded.

Inclusion criteria were: (1) an acute hamstring muscle injury sustained during an official professional football match and confirmed by magnetic resonance imaging; (2) clear identification of the injury-inciting action on video; (3) occurrence of the injury during a sprint action reaching a peak running speed of $\geq 21 \text{ km} \cdot \text{h}^{-1}$, lasting $\geq 1.5 \text{ s}$, and attaining $\geq 60\%$ of the player's maximal pre-injury season speed (4) completion of $> 10 \text{ min}$ of match play and availability of at least 2 additional non-injury sprint actions performed by the same player during the same match, each meeting the same eligibility criteria of $\geq 21 \text{ km} \cdot \text{h}^{-1}$, $\geq 1.5 \text{ s}$ in duration, and $\geq 60\%$ of maximal pre-injury season speed. Goalkeepers were excluded because their match demands and injury mechanisms differ substantially from those of outfield players [17, 23].

Data collection of external loads and video during match play

Match external load variables and videos were obtained from a synchronised multicamera tracking system called Mediacoach® (official digital platform of *LaLiga*, Madrid, Spain). Mediacoach® is a reliable and valid system [24–26] based on TRACAB Gen5 optical video tracking system (ChyronHego, New York, USA) which uses sixteen strategically positioned cameras to continuously track all players on the pitch throughout the match, for assessing external load metrics in elite football when compared with GPS–IMU technology, specifically WIMU Pro (Hudl, Lincoln, NE, USA), and with an infrared camera-based three-dimensional motion capture system, VICON Nexus Version 2.3 (VICON, Oxford, UK) [24–26].

Mediacoach® integrates match video with player-position data obtained from the TRACAB Gen5 optical tracking system at 25 Hz. Sprint actions were identified using the start and end timestamps of the provider-defined tracking events. Peak speed within each sprint action was the highest processed speed value reported by within event, rather than a value calculated from an isolated raw frame. Speed and acceleration data were exported after TRACAB/Mediacoach processing, and no additional filtering or smoothing was applied by the investigators. The injury moment was identified from the synchronised video, and the tracking event containing this timestamp was selected as the injury sprint (Fig. 2). Eligible controls were then ranked by peak speed, with similarity in duration to the injury sprint used as the secondary selection criterion.

Mediacoach® was used to quantify the kinematic characteristics of injury and to collect match external load data. The following external load variables were selected for analysis: sprint duration (s), initial speed ($\text{km} \cdot \text{h}^{-1}$), peak speed ($\text{km} \cdot \text{h}^{-1}$), mean speed ($\text{km} \cdot \text{h}^{-1}$), peak acceleration ($\text{m} \cdot \text{s}^{-2}$), mean acceleration ($\text{m} \cdot \text{s}^{-2}$) and speed at peak acceleration.

Measurements

Normalised sprint speed

Peak match speed was defined as the highest instantaneous running speed recorded for the player during the match in which the injury occurred. Maximal pre-injury season speed was defined as the highest instantaneous running speed recorded for the player earlier in the same season, excluding the injury sprint and the entire injury match. Normalised sprint speed was calculated using two player-specific reference values. The primary reference was maximal pre-injury season speed (Formula 1).

$$\text{Pre-injury}\backslash\text{:season-normalised}\backslash\text{:speed} = \frac{\text{peak}\backslash\text{:speed}\backslash\text{:during}\backslash\text{:the}\backslash\text{:sprint}}{\text{maximal}\backslash\text{:speed}\backslash\text{:recorded}\backslash\text{:before}\backslash\text{:the}\backslash\text{:injury}\backslash\text{:season}\backslash\text{:match}} \times 100$$

This pre-injury season reference was selected to provide a denominator independent of the case and control sprints included in each matched set [16, 19]. A secondary normalised-speed variable was calculated relative to the player's peak speed recorded during the injury match. Because the match-derived denominator could include either the injury sprint or one of the selected controls, analyses based on peak match speed were considered secondary.

Video acquisition and analysis

Regarding match videos, broadcast footage and the official tactical camera were used when available. Broadcast videos were recorded at 720p and 25 frames per second, while tactical camera videos were recorded at 1080p and 25 frames per second. Injury events were available from multiple camera angles and replays, allowing detailed assessment of the injury-inciting action. The injury moment was identified as the instant at which the player interrupted the sprint or showed signs compatible with acute hamstring injury, such as immediate deceleration, cessation of running, altered gait or a pain-related gesture [7, 13–15]. For each confirmed hamstring muscle injury, the video footage was retrieved and trimmed to approximately 15 s before and 5 s after the injury event. This time window was selected based on previous research[27] and in order to provide sufficient situational context before the injury. Videos were reviewed at normal speed and in slow motion when required using Kinovea software (Version 2023 1.2; www.kinovea.org). This video analysis was performed independently by two experienced observers (TU and VMP) with five to ten years of experience in video analysis research. Inter-rater reliability was assessed before consensus using Cohen's kappa for categorical variables and intraclass correlation coefficients (ICC1,3) for continuous or ordinal variables, as appropriate. Inter-rater reliability was strong for categorical variables ($\kappa > 0.85$; 95% CI: 0.66–1.00), except for short-axis field location ($\kappa = 0.76$; 95% CI: 0.42–0.93) [28]. Reliability for continuous variables was also good-to-excellent (ICC > 0.89 ; 95% CI: 0.64–1.00) [29]. Following independent assessments, both observers met to reach consensus on all variables, with a third reviewer (AMI) consulted in the event of disagreement.

The video-analysis variables included specifically playing position, contact mechanism, ball possession, kinetic chain and match timing [7, 13, 27]. According to previous studies [7, 13, 30], the contact mechanism was classified as non-contact, indirect contact, or direct contact. Ball possession was classified according to whether the injured player had possession at the time of injury. Kinetic chain was classified as open when the foot was not in contact with the ground at the presumed injury moment and closed when ground contact was present. Kinetic chain classification was based on the presumed injury frame identified from video and should therefore be interpreted as an approximation of the sprint-cycle phase rather than a direct biomechanical measurement. Match timing was grouped into 15 min intervals.

Statistical analysis

Continuous variables were summarised as mean±standard deviation (SD). Categorical variables were presented as frequencies and percentages. For descriptive paired comparisons, the values from the 2 matched control sprints were averaged within each matched set for each continuous variable, yielding 1 control value per injury event. In the conditional logistic regression analyses, however, the 2 control sprints were retained as separate observations. Each injury sprint and its 2 matched controls constituted 1 stratum, thereby accounting for the 1:2 matched design. Paired t-tests were used to compare injury and matched control sprints. Effect sizes were expressed as Cohen's *d* for paired data and interpreted as very small (< 0.2), small (0.2–0.49), moderate (0.50–0.79) and large (> 0.80) [31].

The primary analysis examined peak sprint speed normalised to the player's maximal pre-injury season speed using conditional logistic regression. Conditional logistic regression was then used to estimate the association between sprint characteristics and injury occurrence while accounting for the matched design. Odds ratios were expressed per 10-percentage point increase and reported with 95% confidence intervals. Absolute peak and mean speed, initial speed, speed at maximal acceleration, maximal and mean acceleration, sprint duration, and speed normalised to peak match speed were examined in separate secondary conditional logistic regression models.

To aid clinical interpretation, normalised speed was categorised using predefined thresholds of $\geq 85\%$, $\geq 90\%$ and $\geq 95\%$ of the player's maximal pre-injury season and peak match speeds. All threshold-based models were considered exploratory. Match-

normalised threshold analyses were interpreted with particular caution because the peak-match reference was derived from the same match as the case and control sprints and was therefore not fully independent of the selection procedure.

RESULTS

The 40 injury events occurred in 34 players. Four players sustained one subsequent new injury event, whereas one player sustained two subsequent new events. Among the five players with multiple injury events, one sustained injuries involving the same muscle and anatomical location in contralateral limbs (right and left distal biceps femoris); one sustained injuries involving the same muscle but different anatomical locations and limbs (proximal biceps femoris in the left limb and distal biceps femoris in the right limb); two sustained injuries involving the same muscle and limb but different anatomical locations (proximal and distal biceps femoris); and one sustained injuries involving different hamstring muscles, limbs and anatomical locations (distal semitendinosus in the right limb, distal biceps femoris in the left limb and proximal semimembranosus in the left limb). None met the prespecified definition of an early recurrent injury.

Among the 40 MRI-confirmed hamstring muscle injuries, 33 involved the biceps femoris long head (82.5%), 3 the semitendinosus (7.8%), 3 the semimembranosus (7.5%), and 1 multiple hamstring muscles (2.5%). Regarding anatomical location, 13 injuries were proximal (32.5%), 4 involved the middle third (10%), and 23 were distal (57.5%). The median time loss was 30.13 days (IQR: 16.75–39.50; range: 4–66 days), with 2 injuries classified as mild, 14 as moderate, and 24 as severe according to the prespecified time-loss categories.

Contextual video-analysis and external kinematic characteristics

The descriptive video analysis showed that sprint-related hamstring muscle injuries occurred most frequently in defenders (42%), followed by forwards (32%) and midfielders (25%), although the distribution across playing positions was not statistically significant ($\chi^2=1.85$, $p = 0.397$). Most injuries occurred through non-contact mechanisms (95%; $\chi^2=32.40$, $p < 0.001$), without ball possession (72%; $\chi^2=8.10$, $p = 0.004$), and during open kinetic-chain actions (75%; $\chi^2=31.40$, $p < 0.001$). Standardised residual analysis indicated that non-contact injuries, injuries without ball possession, and open kinetic-chain actions occurred more frequently than expected, whereas indirect-contact injuries, injuries with ball possession and closed kinetic-chain or unsure actions occurred less frequently than expected (all $p < 0.050$). Injuries were distributed across match-minute periods without evidence of clustering in a specific 15-min interval ($\chi^2=5.30$, $p = 0.380$; Fig. 3).

Regarding external kinematic characteristics, both injured and control sprints involved a duration of at least 4.2 ± 2.4 s and 4.2 ± 2.4 s, an initial speed of 12.6 ± 6.3 km · h⁻¹ and 11.0 ± 4.8 km · h⁻¹, peak speed of 27.2 ± 3.7 km · h⁻¹ and 26.0 ± 3.3 km · h⁻¹, reached the $85 \pm 12\%$ and $81 \pm 11\%$ of the player's maximum speed recorded during the season, a peak acceleration of 4.3 ± 4.1 m · s⁻² and 4.7 ± 4.6 m · s⁻², a mean acceleration of 1.0 ± 2.2 m · s⁻² and 1.1 ± 2.2 m · s⁻² and 16.8 ± 4.8 km · h⁻¹ and 16.5 ± 4.5 km · h⁻¹ of speed at peak acceleration, respectively.

Normalised and absolute sprint speed and other kinematic characteristics

Injury sprints occurred at a higher percentage of the player's maximal pre-injury season speed than matched control sprints ($85.0 \pm 12.0\%$ vs $81.1 \pm 10.1\%$). The paired mean difference was 3.89 percentage points (95% CI 0.42 to 7.36; $p = 0.029$). In the primary conditional logistic regression analysis, each 10-percentage point increase in pre-injury season-normalised speed was associated with higher odds that the sampled sprint was injury-related (OR = 2.01, 95% CI 1.09 to 3.71; $p = 0.025$).

In the secondary match-normalised analysis, injury sprints were performed at a higher percentage of the player's peak match speed than matched controls ($92.5 \pm 9.6\%$ vs $88.7 \pm 9.5\%$). The paired mean difference was 3.82 percentage points (95% CI 0.37 to 7.26; $p = 0.031$). Each 10-percentage point increase in match-normalised speed was associated with higher odds that the sampled sprint was injury-related (OR = 1.91, 95% CI 1.07 to 3.38; $p = 0.027$).

Injury sprints also showed a higher absolute peak speed than matched control sprints (27.2 ± 3.7 km · h⁻¹ vs 26.0 ± 3.0 km · h⁻¹). In the paired analysis (Table 1), the mean difference was 1.19 km · h⁻¹ (95% CI 0.08 to 2.30; $p = 0.036$). Conditional logistic

regression (Table 2) indicated that each $1 \text{ km} \cdot \text{h}^{-1}$ increase in peak sprint speed was associated with 23% higher odds that the sprint was injury-related (OR = 1.23, 95% CI 1.02 to 1.49; $p = 0.030$). The injury sprint was equal to or superior to the player's pre-injury maximal-speed action of the season in 6 of 40 injury cases (15%) and in 4 of 80 control cases (5%) (Fig. 1F). In addition, the injury sprint was the highest peak-speed action of the match in 20 of 40 injury cases (50%). In the remaining cases (50%), at least one non-injury sprint reached a higher peak speed than the corresponding injury sprint.

Table 1
Kinematic characteristics of injury and matched control sprints.

Variable	Injury sprint, mean $\pm$ SD	Matched control sprint, mean $\pm$ SD	Paired mean difference	95% CI	p value	Cohen's dz
% maximal pre-injury season speed	85.0 $\pm$ 12.0	81.1 $\pm$ 10.1	3.89	0.42 to 7.36	0.029	0.36
% peak match speed	92.5 $\pm$ 9.6	88.7 $\pm$ 9.5	3.82	0.37 to 7.26	0.031	0.35
Peak sprint speed, $\text{km} \cdot \text{h}^{-1}$	27.2 $\pm$ 3.7	26.0 $\pm$ 3.0	1.19	0.08 to 2.30	0.036	0.34
Mean speed, $\text{km} \cdot \text{h}^{-1}$	21.1 $\pm$ 3.8	19.5 $\pm$ 3.5	1.56	0.05 to 3.07	0.043	0.33
Initial speed, $\text{km} \cdot \text{h}^{-1}$	12.6 $\pm$ 6.3	11.0 $\pm$ 4.8	1.55	-0.65 to 3.74	0.162	0.23
Speed at maximal acceleration, $\text{km} \cdot \text{h}^{-1}$	16.8 $\pm$ 4.8	16.5 $\pm$ 4.45	0.34	-1.33 to 2.00	0.685	0.06
Maximal acceleration, $\text{m} \cdot \text{s}^{-2}$	4.3 $\pm$ 4.1	4.7 $\pm$ 4.5	-0.36	-1.01 to 0.29	0.269	-0.18
Mean acceleration, $\text{m} \cdot \text{s}^{-2}$	0.9 $\pm$ 2.2	1.0 $\pm$ 2.1	-0.09	-0.51 to 0.33	0.656	-0.07
Sprint duration, s	4.2 $\pm$ 2.4	4.2 $\pm$ 2.2	0.00	-0.50 to 0.50	0.997	0.00
Values are presented as mean $\pm$ SD unless otherwise stated. Mean differences refer to paired comparisons between injury sprints and the mean of the two matched control sprints. CI, confidence interval; $\text{km} \cdot \text{h}^{-1}$, kilometres per hour; $\text{m} \cdot \text{s}^{-2}$, metres per second squared; SD, standard deviation; s, seconds						

Table 2
Conditional logistic regression models for sprint characteristics

Predictor	Scale	OR	95% CI	p value
% maximal pre-injury season speed	Per 10 percentage points	2.01	1.09 to 3.71	0.025
% peak match speed	Per 10 percentage points	1.91	1.07 to 3.38	0.027
Peak speed	Per 1 km · h ⁻¹	1.23	1.02 to 1.49	0.030
Mean speed	Per 1 km · h ⁻¹	1.12	1.01 to 1.26	0.041
Initial speed	Per 1 km · h ⁻¹	1.05	0.98 to 1.12	0.177
Speed at maximal acceleration	Per 1 km · h ⁻¹	1.02	0.93 to 1.12	0.668
Maximal acceleration	Per 1 m · s ⁻²	0.88	0.69 to 1.12	0.283
Mean acceleration	Per 1 m · s ⁻²	0.90	0.61 to 1.35	0.620
Sprint duration	Per 1 s	1.00	0.75 to 1.33	0.997
Odds ratios were estimated using conditional logistic regression, which accounted for the matched design. Normalised-speed variables are expressed per 10-percentage point increase. CI, confidence interval; km · h ⁻¹ , kilometres per hour; m/s ² , metres per second squared; OR, odds ratio.				

Mean sprint speed was similarly higher during injury sprints than during matched control sprints (21.1 ± 3.8 km · h⁻¹ vs 19.5 ± 3.5 km · h⁻¹). The paired mean difference was 1.56 km · h⁻¹ (95% CI 0.05 to 3.07; $p = 0.043$). In the conditional logistic regression analysis, each 1 km · h⁻¹ increase in mean speed was associated with 12% higher odds that the sprint was injury-related (OR = 1.12, 95% CI 1.01 to 1.26; $p = 0.041$).

Initial speed, speed at maximal acceleration, maximal acceleration, mean acceleration and sprint duration did not show clear associations with injury occurrence in either the paired comparisons or conditional logistic regression analyses (Tables 1 and 2).

Normalised-speed thresholds

When the thresholds were calculated relative to maximal pre-injury season speed, 47.5% of injury sprints and 33.8% of control sprints reached at least 85% of maximal season speed (OR = 3.80, 95% CI 1.01 to 14.33; $p = 0.049$). In contrast, the associations were less precise for the higher season-normalised thresholds. Overall, 32.5% of injury sprints and 27.5% of controls reached at least 90% of maximal season speed (OR = 1.56, 95% CI 0.49 to 4.93; $p = 0.452$), whereas 25.0% of injury sprints and 13.8% of controls reached at least 95% of maximal season speed (OR = 2.90, 95% CI 0.85 to 9.88; $p = 0.088$).

In the secondary match-normalised analyses, a greater proportion of injury sprints reached or exceeded the predefined peak match-speed thresholds than matched control sprints (Table 3). Overall, 82.5% of injury sprints and 68.8% of control sprints reached at least 85% of peak match speed (OR = 3.80, 95% CI 1.01 to 14.33; $p = 0.049$). Similarly, 72.5% of injury sprints reached at least 90% of peak match speed compared with 53.8% of control sprints (OR = 4.16, 95% CI 1.31 to 13.23; $p = 0.016$), while 55.0% of injury sprints reached at least 95% of peak match speed compared with 33.8% of controls (OR = 4.46, 95% CI 1.43 to 13.97; $p = 0.010$). Given the wide confidence intervals, particularly in the threshold-based models, these findings should be interpreted as exploratory.

Table 3
Exploratory normalised-speed threshold analysis

Threshold	Injury sprints	Control sprints	OR	95% CI	p value
≥ 85% maximal season speed	47.5%	33.8%	3.80	1.01 to 14.33	0.049
≥ 90% maximal season speed	32.5%	27.5%	1.56	0.49 to 4.93	0.452
≥ 95% maximal season speed	25.0%	13.8%	2.90	0.85 to 9.88	0.088
≥ 85% maximal match speed	82.5%	68.8%	3.80	1.01 to 14.33	0.049
≥ 90% maximal match speed	72.5%	53.8%	4.16	1.31 to 13.23	0.016
≥ 95% maximal match speed	55.0%	33.8%	4.46	1.43 to 13.97	0.010
Odds ratios were estimated using conditional logistic regression, accounting for the matched design. Thresholds represent the proportion of each sprint normalised to the player's peak match or maximal season speed. Threshold models based on maximal match speed should be interpreted cautiously because the reference value was derived from the same match as the sampled injury and control sprints and was not fully independent of the control-selection procedure. CI, confidence interval; OR, odds ratio; ≥, greater than or equal to					

DISCUSSION

The principal objective of this study was to determine whether sprint-related hamstring muscle injuries in professional football occur during actions performed at higher pre-injury season-normalised speed running speeds compared with matched non-injury sprints from the same player. The rationale for this investigation was based on previous reports suggesting that absolute speed may represent a different physiological and mechanical demand depending on the player's maximal speed capacity [19]. The main finding was that injury sprints were performed approximately 3.9 percentage points closer to the player's maximal pre-injury season speed, with a small standardised paired difference. In the primary conditional logistic regression analysis, each 10-percentage point increase in pre-injury season-normalised speed was associated with approximately twofold higher odds that the sampled sprint was injury-related. Absolute peak and mean sprint speeds showed associations in the same direction. A similar result was observed when speed was normalised to peak match speed, although this secondary analysis requires additional caution because its reference value was obtained from the same match as the injury and control sprints.

The match-normalised threshold analyses suggested a greater frequency of injury sprints than control sprints above the predefined cut-offs (i.e., ≥ 85%: 82.5% vs 68.8%; ≥90%: 72.5% vs 53.8%; and ≥ 95%: 55.0% vs 33.8%). However, these findings do not provide independent evidence of a specific injury threshold. When the injury sprint represented the player's peak-speed action during the match in which the injury occurred, its match-normalised value was necessarily 100%, whereas the selected control sprints were necessarily lower. Importantly, the injury sprint was the highest-speed action of the match in only 20 of the 40 injury cases (50%). In the remaining 20 cases, the player completed at least one faster sprint during the same match without sustaining a hamstring injury. This observation illustrates that higher or near-maximal running speed does not, in isolation, distinguish an injurious from a successfully completed sprint and argues against interpreting any single normalised-speed value as a causal or clinically actionable injury threshold. Rather, running speed should be considered one characteristic of the injury-inciting action that may interact with other time-varying factors, including sprint mechanics, fatigue, tactical context, neuromuscular status and tissue capacity. Additionally, because the peak-match denominator was partly dependent on both case status and the control-selection procedure, the resulting match-normalised differences and threshold odds ratios may reflect, at least in part, the structure of the matching algorithm rather than a purely physiological distinction between injury and non-injury sprints. For this reason, the pre-injury season-normalised analysis, which used a reference speed recorded before and outside the injury match, should be considered the more methodologically robust finding. Therefore, the practical value of normalised speed may lie less in identifying a 'dangerous' threshold than in characterising the intensity of the injury-inciting action relative to the player's individual running capacity within a broader, multifactorial context.

Normalised and absolute sprint speed and other kinematic characteristics

Previous video-analysis and GPS studies have consistently identified sprinting and high-speed running as major injury-inciting actions for hamstring muscle injuries in professional football [7–9, 13, 27]. These findings are biomechanically plausible because the hamstrings are exposed to high eccentric forces during late swing and early stance [10, 32], particularly when running speed approaches maximal values [7, 9]. Our study extends this evidence by comparing injury sprints with non-injury sprints performed by the same player and objectively quantifying external load metrics. Absolute and normalised speed measures were modestly higher in injury than in matched control sprints, whereas initial speed, speed at maximal acceleration, acceleration-related variables and sprint duration did not show clear associations. This pattern suggests that the observed associations were clearer for peak and mean speed than for the measured acceleration variables. Nevertheless, the absence of clear associations for the remaining variables should not be interpreted as evidence that acceleration, fatigue or sprint mechanics are unimportant, because the confidence intervals remained compatible with potentially meaningful effects and tracking-derived acceleration measures may be particularly sensitive to measurement error.

The paired effect sizes for normalised and absolute speed were small, despite the larger odds ratios obtained from the conditional logistic regression models. These results describe related but different quantities: the paired analyses quantify the average within-set difference, whereas conditional logistic regression estimates how the odds that a sampled sprint was injury-related changed across the observed range of the predictor. Consequently, the magnitude of the odds ratios should not be interpreted as indicating that a 10-percentage point increase doubles a player's prospective risk of injury during any future sprint.

Normalised-speed selection

Using maximal pre-injury season and peak match speed as reference values provided different forms of information. The pre-injury season maximum offered an external competition-derived reference that was independent of the injury and control sprints, whereas peak match speed described each sprint relative to the fastest action occurring within that same match. Although both continuous models showed associations in the same direction, the latter reference was susceptible to mathematical coupling with the selection of the case and controls.

Accordingly, the agreement between the season- and match-normalised continuous analyses may be viewed as supportive, but the match-normalised estimates should not be interpreted as independent confirmation of the primary result. The particularly large odds ratios obtained from the match-normalised threshold models may have been amplified by this dependency.

Although injury sprints more frequently exceeded 85%, 90% and 95% of peak match speed, the wide confidence intervals indicate considerable uncertainty. Moreover, because the match-derived denominator was not independent of the sampled sprints, these estimates cannot be used to identify a physiological or clinically actionable injury threshold. Analysing speed continuously relative to an independent pre-injury reference currently provides a more defensible representation of the observed association.

Normalised speed threshold

The distinction between absolute and normalised speed is clinically important [16, 19]. An absolute speed threshold may classify two players as performing the same sprint demand despite substantial differences in their individual maximal speed. A player running at $28 \text{ km} \cdot \text{h}^{-1}$ may be close to maximal capacity, while another may be operating well below his maximal sprint speed. Normalised speed, therefore, provides a more individualised estimate of the mechanical demand experienced by the hamstring muscle–tendon unit [19] and it may improve physiological interpretability and between player comparability [33]. However, normalised running speed remains an indirect proxy and should not be interpreted as a direct measure of hamstring muscle–tendon force, strain or tissue capacity.

Using both peak match and maximal season speed as reference values provided complementary information. Maximal season speed may offer a relatively stable competition-derived reference of the player's observed speed capacity, whereas maximal match speed reflects the intensity of the sprint relative to what the player achieved within that specific match. The similar continuous associations obtained using both references strengthen the overall finding. In contrast, the different patterns observed in the threshold analyses indicate that the interpretation of categorical cut-offs is sensitive to the reference value selected. Although injury sprints more frequently exceeded 85%, 90% and 95% of maximal match speed, the wide confidence intervals indicate considerable uncertainty. The season-normalised threshold results were also inconsistent, with a clearer association at $\geq 85\%$ but imprecise estimates at $\geq 90\%$ and $\geq 95\%$. Accordingly, the present data do not support selecting $\geq 90\%$, $\geq 95\%$ or any other value as

a definitive injury threshold. Analysing normalised speed as a continuous variable currently provides a more robust representation of the observed association than dichotomising the same exposure at several nested cut-offs.

Contextual video-analysis characteristics

The descriptive video analysis showed that sprint-related hamstring muscle injuries occurred most frequently in defenders (42%), followed by forwards (32%) and midfielders (25%). However, the distribution by playing position was not statistically significant, and the present results therefore provide no clear evidence that one positional group was disproportionately represented. Within the injury sample, most events occurred through non-contact mechanisms (95%), without ball possession (72%) and during open kinetic-chain actions (75%). These categories occurred more frequently than expected in the corresponding categorical analyses. Injuries were distributed across the different match periods, without evidence of clustering within a particular 15-min interval. This pattern is consistent with previous video-analysis studies in professional football, which have identified high-speed running and non-contact sprinting as the predominant injury-inciting circumstances [7, 15]. The predominance of events without ball possession may reflect sprint actions in which players were responding to an opponent, moving into space or performing defensive transitions rather than carrying the ball [8, 13]. However, tactical context was not compared with the frequency of equivalent non-injury match actions, and these interpretations should therefore remain descriptive.

From a biomechanical perspective, the high frequency of open kinetic-chain injuries is plausible, as the hamstrings are exposed to substantial eccentric loading during terminal swing while decelerating knee extension before ground contact [10, 32]. Nevertheless, the video-based classification of an action as an open kinetic chain does not directly determine the precise phase of tissue failure, and the study did not include musculoskeletal modelling or direct measurements of muscle–tendon loading. Importantly, the contextual percentages represent the distribution of characteristics among the observed injury events, supporting previous evidence and reinforce the value of video analysis for identifying the match contexts that precede sprint-related hamstring muscle injuries in elite football [7, 13, 27]. However, in the absence of exposure denominators for each playing position, possession state or kinetic-chain category, they should not be interpreted as estimates of comparative injury risk.

Clinical implications

These findings suggest that pre-injury season-normalised speed may provide useful complementary information when practitioners describe and monitor sprint demands in professional football [9, 19]. Monitoring absolute speed alone may overlook whether a given action was relatively close to the player's observed maximal capacity. However, the present study does not establish that a particular normalised-speed value represents a dangerous threshold or that reducing exposure above that value would prevent injury. The higher frequency of injury sprints above the predefined match-normalised thresholds should therefore not be used to define rigid speed limits. Similarly, the findings should not be interpreted as evidence that exposure above 85%, 90% or 95% of maximal speed should be avoided. High-speed and near-maximal sprinting are inherent demands of professional football, and insufficient exposure may itself leave players inadequately prepared for competition [34]. Instead, normalised-speed information could be considered alongside recent sprint exposure, previous injury, symptoms, strength, fatigue, sprint mechanics and return-to-play status.

In line with previous literature [35], rehabilitation programmes and return to play decision-making commonly include progressive exposure to high and near-maximal sprinting before full match reintegration. The present findings are compatible with this approach because injury actions tended to occur at relatively high individual speeds. However, this study did not evaluate rehabilitation programmes, readiness criteria or the effects of sprint exposure on subsequent injury incidence.

The contextual video-analysis findings may also inform prevention strategies. The predominance of injuries without direct contact [8], without ball possession [15] and during open kinetic-chain actions [13] suggests that sprint-related hamstring muscle injuries frequently occur in high-intensity running situations where the player is reacting to game demands rather than controlling the ball. This may be particularly relevant for defenders and players involved in recovery runs, defensive transitions or actions requiring rapid pursuit of an opponent [8]. However, these scenarios should be viewed as potentially relevant movement contexts rather than demonstrated causal mechanisms or independently validated prevention targets.

Strengths and limitations

The main strength of this study is the matched case–control design, which allowed injury sprints to be compared with non-injury sprints from the same player. This reduces between-player variability in maximal speed capacity, anthropometrics and playing role. Another strength is the combination of systematic video analysis with tracking-derived sprint metrics, allowing both contextual and kinematic characteristics to be examined.

Several limitations should be considered. First, although the final sample included 40 injury events and exceeded the design-based target established for the principal conditional logistic regression analysis, it remained modest for secondary analyses, categorical thresholds and more complex modelling. The 40 injury events arose from 34 unique players, meaning that some players contributed more than one event. This may have introduced residual within-player dependency beyond the individual matched-set structure. The number of repeated events was insufficient to support reliable multilevel or frailty modelling, and the results should therefore continue to be interpreted cautiously. Second, although each injury sprint was matched with two control sprints from the same player, residual differences in tactical context, fatigue, opponent pressure or match state may remain. The within-player design controls for stable player-level characteristics but does not control for all time-varying circumstances surrounding each sprint.

Third, the controls were selected according to predefined criteria to provide sprint actions of comparable duration and relatively high speed. Conditional odds ratios therefore describe differences between the sampled injury sprints and these specifically selected control sprints; they should not be interpreted as estimates of the absolute or prospective risk of injury across all sprint exposures. The control-selection process may also have reduced the contrast between groups by selecting relatively demanding non-injury actions. Fourth, peak match and maximal season speeds may not represent the player's true physiological sprint capacity. They are competition-derived reference values and depend on the matches observed, playing time, tactical role and opportunities to reach maximal speed. Normalised-speed values should therefore be interpreted relative to the player's recorded competitive maximum rather than as percentages of a directly measured physiological maximum. Fifth, several correlated continuous predictors and nested speed thresholds were examined in separate models. Although the threshold analyses were prespecified and interpreted using effect estimates and confidence intervals, multiple exploratory comparisons increase the possibility of chance findings. Threshold models based on peak match speed were additionally affected by the dependency between the denominator and the case–control selection process. Finally, we could not determine whether players had pre-existing symptoms, residual fatigue, neuromuscular impairment or subclinical tissue damage before the injury sprint. Therefore, higher normalised speed should be interpreted as a characteristic of the injury-inciting action rather than as an isolated causal mechanism.

Future research

Future studies should replicate these findings in larger samples and across different leagues, teams and competitive levels. Larger datasets would permit the use of multilevel models accounting for repeated injury events within players and allow more precise estimation of threshold-based associations. Prospective studies should record the complete distribution of training and match sprint exposures, rather than selected injury and control actions alone, to determine whether the frequency, timing or absence of near-maximal sprint exposure is associated with subsequent hamstring injury incidence. Future work should also compare competition-derived maximal speeds with speeds obtained during standardised sprint testing and examine whether the choice of reference value influences the interpretation of normalised intensity. Further research should also explore how sprint context, fatigue, neuromuscular status and previous injury interact with normalised speed to influence injury occurrence. A specific normalised-speed threshold should not be adopted clinically until it has been replicated in independent samples and evaluated prospectively against appropriate exposure denominators.

CONCLUSIONS

In this retrospective matched case–control study, sprint-related hamstring muscle injury actions were performed at modestly higher absolute and pre-injury season-normalised speeds than matched non-injury sprints performed by the same player. Each 10-percentage point increase in speed normalised to the player's maximal pre-injury season speed was associated with approximately twofold higher odds that the sampled sprint was injury-related. A similar association was observed in the secondary match-normalised analysis, although this estimate was susceptible to mathematical coupling. These estimates describe an association within the selected injury and control sprints and should not be interpreted as prospective injury-risk estimates.

Speed normalised to peak match speed showed a similar continuous association, but this analysis was susceptible to mathematical coupling because the reference value was obtained from the same match actions used to select the cases and controls. The match-normalised threshold findings should therefore be considered particularly exploratory and do not identify a causal, predictive or clinically actionable injury threshold. Prospective studies incorporating complete sprint-exposure data are required to determine whether normalised speed contributes to injury prediction, prevention or return-to-play decision-making. Accordingly, normalised speed may be most useful for characterising the relative intensity of an injury-inciting sprint within the player's individual running profile, rather than for identifying a discrete speed threshold above which hamstring injury should be expected.

Abbreviations

Abbreviation

Definition

CI

Confidence interval

GPS

Global Positioning System

ICC

Intraclass correlation coefficient

IMU

Inertial measurement unit

IQR

Interquartile range

MRI

Magnetic resonance imaging

OR

Odds ratio

SD

Standard deviation

STROBE-SIIS

Strengthening the Reporting of Observational Studies in Epidemiology – Sports Injury and Illness Surveillance

Declarations

Clinical trial number

Not applicable.

Ethics approval and consent to participate

This study was reviewed and approved by the Institutional Review Board of Miguel Hernandez University (Spain), under the latest version of the Declaration of Helsinki (code: DPC. VMP.240213). Informed consent was obtained from all subjects involved in the study.

Consent for publication

Not applicable.

Competing interests

All authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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Author Contributions Statement

A.M-I. contributed to conceptualisation, data curation, formal analysis and the writing of the draft manuscript. T.U was involved in the literature review and reviewing/editing of the draft of the manuscript. J.D.C. contributed to data curation, formal analysis and reviewing/editing of the draft of the manuscript. R.L-D.C. contributed to the conceptualisation, data curation, formal analysis, and the reviewing/editing of the draft of the manuscript and supervision. R.R. was involved in data curation and formal analysis. V.M-P. supported the conceptualisation and study design, the reviewing/editing of the draft manuscript and supervision. All authors read and approved the final version of the article and agree with the authors' order of submission.

Author Contribution

A.M-I. contributed to conceptualisation, data curation, formal analysis and the writing of the draft manuscript. T.U was involved in the literature review and reviewing/editing of the draft of the manuscript. J.D.C. contributed to data curation, formal analysis and reviewing/editing of the draft of the manuscript. R.L-D.C. contributed to the conceptualisation, data curation, formal analysis, and the reviewing/editing of the draft of the manuscript and supervision. R.R. was involved in data curation and formal analysis. V.M-P. supported the conceptualisation and study design, the reviewing/editing of the draft manuscript and supervision. All authors read and approved the final version of the article and agree with the authors' order of submission.

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Data Availability

The datasets generated and/or analysed during the current study are not publicly available due ethical restrictions related to participant confidentiality and the approved study protocol but are available from the corresponding author on reasonable request.

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Figures

A. Season timeline (38 match days)



Maximal season sprint
35.1 km/h

Injury match

B. Injury match (Match day 21)

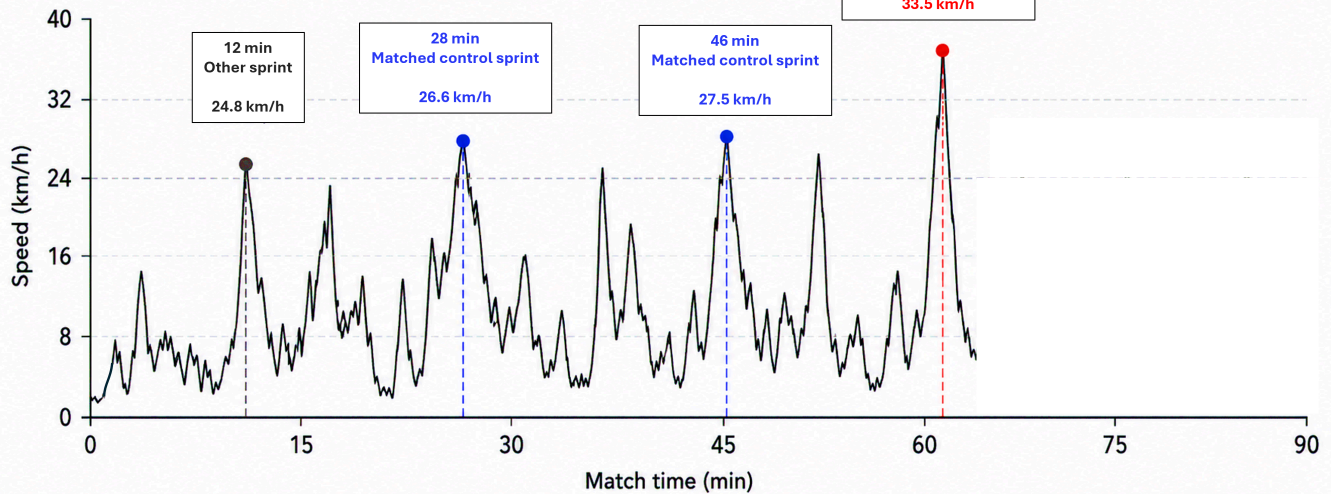


Figure 1

Illustrative example of the retrospective matched within-player case-control design used to identify injury and non-injury sprint actions. Panel A shows the timeline of matches played during the season, highlighting the match in which the player recorded his maximal season sprint speed (blue; match day 8, $35.1 \text{ km} \cdot \text{h}^{-1}$) and the match in which the sprint-related hamstring muscle injury occurred (red; match day 21). Panel B presents the player's speed-time profile during the injury match. The injury sprint was designated as the case sprint (red), while the two highest-speed non-injury sprints of similar effort duration performed by the same player were selected as matched control sprints (blue), thereby allowing each player to serve as his own control.

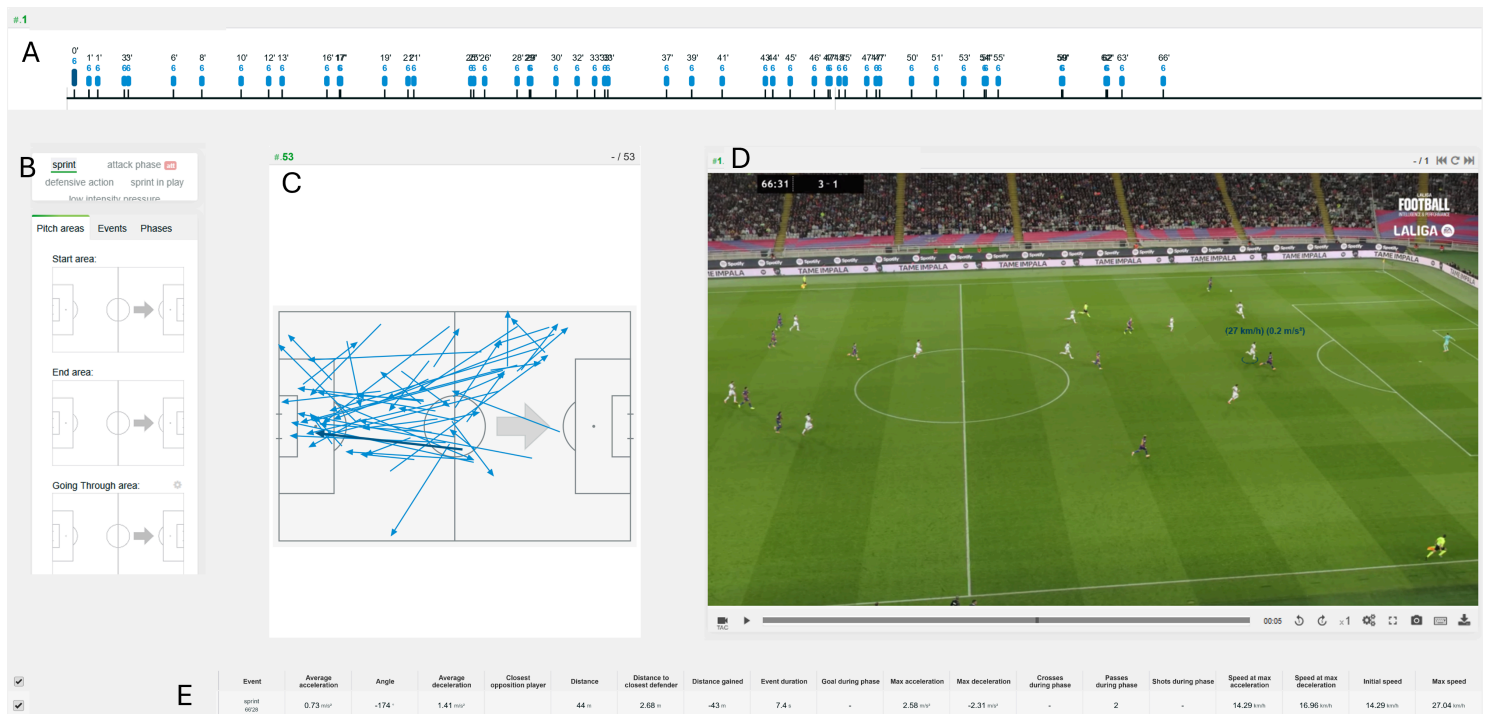


Figure 2

Mediacoach® workflow for the identification, visual verification and characterisation of sprint events during official match play. (A) Temporal distribution of the sprint events detected throughout the match. (B) Event-classification interface used to filter action type and contextual information, including the start and end of the event, pitch areas and phase of play. (C) Spatial representation of all sprint trajectories identified for the selected player, with arrows indicating the direction and displacement of each action. (D) Synchronised match footage used to visually verify and contextualise the selected sprint event, with the player's instantaneous running speed and acceleration superimposed on the video. (E) Event-level output table containing the spatiotemporal, physical and contextual variables extracted for each sprint, including event duration, distance covered, distance gained, running direction, initial and peak speed, and maximal acceleration and deceleration.

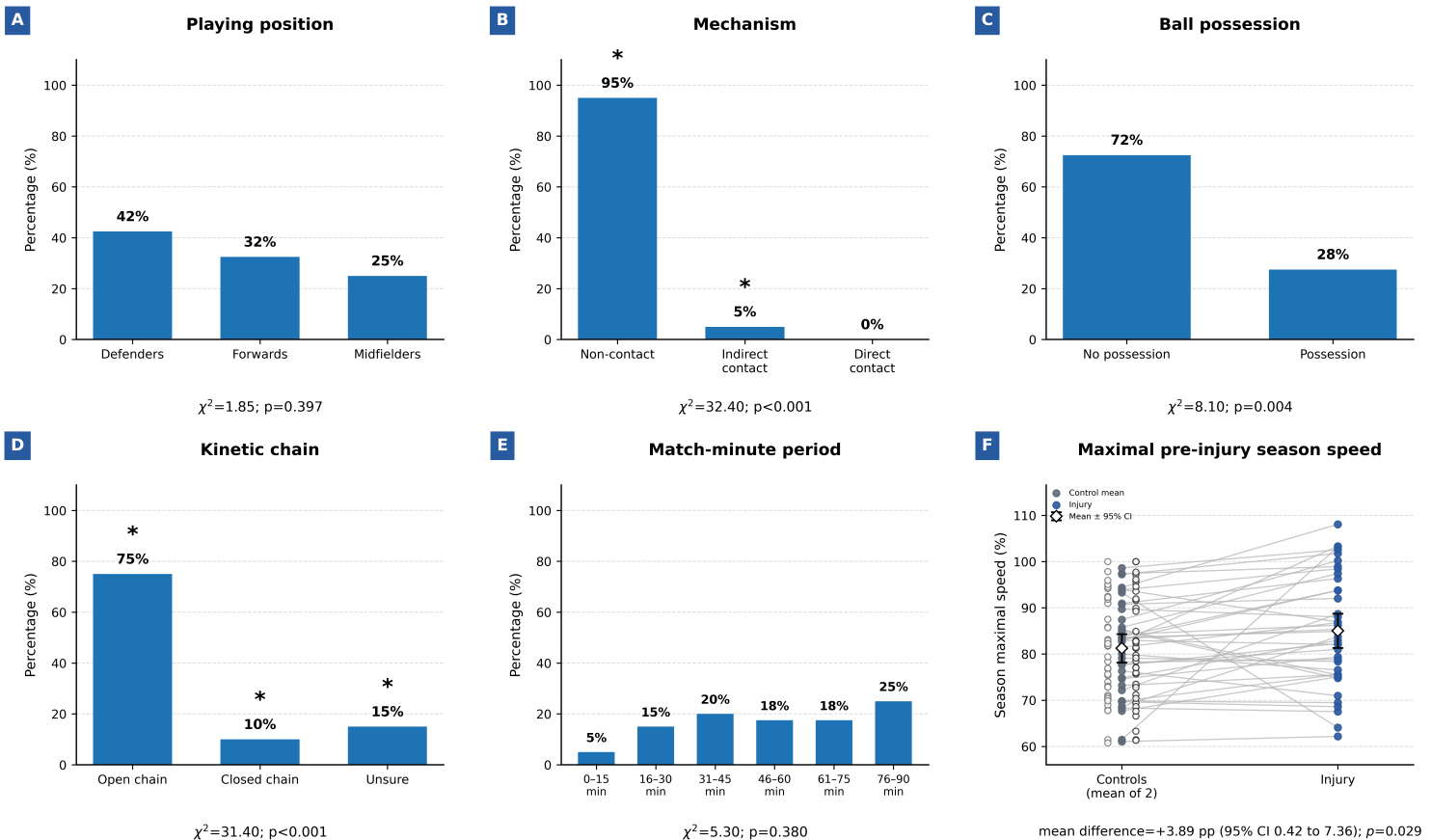


Figure 3

Contextual video-analysis characteristics and individual maximal-speed responses of sprint-related hamstring injuries. (A) Playing position, (B) contact mechanism, (C) ball possession, (D) kinetic chain, (E) match-minute period and (F) individual responses in running speed expressed as a percentage of the maximal pre-injury season speed. Bars represent the percentage of injury events in each category. Asterisks indicate categories whose observed frequency differed significantly from the expected frequency based on standardised residual analysis with Holm correction (*Holm-adjusted* $p<0.05$). In panel F, grey lines connect the mean value of the two matched control sprints with the corresponding injury sprint for each injury event. Open circles represent individual control values, blue circles represent injury-sprint values, and diamonds with error bars represent the group means and their 95% confidence intervals. The mean difference in panel F is expressed in percentage points (pp).

Supplementary Files

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