# Systematic video analysis of 57 hamstring injuries in women's football (soccer): injury mechanisms, situational patterns and biomechanics

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## ABSTRACT

**Objective** To investigate the occurrence and inciting events of hamstring injuries (HSIs) in elite women's football through video analysis, describing the mechanism, situational patterns and biomechanics of the sport-specific activities performed before and at the time of injury.

**Methods** A descriptive observational study was conducted using video analysis of HSIs from top national and international women's football competitions across seven seasons (2017/2018 to 2023/2024). Three raters independently categorised HSIs following the Football Injury Inciting Circumstances Classification System and analysed joint and trunk kinematics.

**Results** Among 109 identified HSIs, 57 (52%) were eligible for analysis. Most injuries (74%) were non-contact, with 51% occurring during running and 49% during stretch-type movements, including kicking and duelling. These patterns involved ball interaction in 68% and duels in 51% of cases. Injuries predominantly occurred in offensive situations (72%), with moderate to high horizontal speed and minimal vertical movement. Biomechanical analysis indicated frequent knee extension and hip flexion.

**Conclusion** HSIs in women's football predominantly occur during movements with high eccentric demand of the hamstring muscles, with non-contact mechanisms being most common. HSIs are not solely linked to high-speed running but can also occur during propulsion and braking phases, or overstretching activities with an open or closed kinetic chain. HSIs often resulted from complex movements involving multiple tasks simultaneously under high physical and mental demands, in unpredictable and evolving scenarios.

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Hamstring injuries (HSIs) are the most common type of injury in football, typically require weeks for recovery, and exhibit a high recurrence rate.

⇒ These injuries are predominantly non-contact or result from indirect contact, often occurring during running or stretch movements.

⇒ While different video analysis studies have described HSIs in male football, female players remain largely underrepresented. This gap limits our understanding of potential sex-specific differences in injury mechanisms and situational patterns.

### WHAT THIS STUDY ADDS

⇒ This study is the first to use video analysis to explore HSIs in elite female footballers, filling knowledge gaps compared with male counterparts.

⇒ We introduced a new classification for the type of mechanical perturbation, distinguishing them as either 'hold/pull' (eg, tackling, body block, hand on shoulder, shirt pulling) or 'hit/push' type (eg, shoulder-to-shoulder, hand or forearm push, body check while pressing).

⇒ A football-specific classification of HSIs was developed, detailing three main situational patterns: run-type, kick-type and duel-type.

⇒ The study highlights that HSIs in match scenarios were often accompanied by technical (ball handling) and/or coordinative (opponent interaction and contact) challenges.

## INTRODUCTION

Sports injuries result from complex interactions of factors (biomechanical, behavioural, physiological, and more) which influence each other over time.[1] In football, this dynamic interplay places players at potential risk,[2–4] with hamstring injuries (HSIs) being among the most common injuries in female players,[5–7] resulting in significant performance and economic burden,[8] potentially affecting career longevity, as observed in male counterparts.[9] Despite efforts from medical staff and the scientific community, HSIs now account for 12% of all time-loss injuries in women's football.[10] Although these injuries generally result in shorter lay-off periods, they impose a notable burden, with approximately 20 days lost per 1000 hours of exposure.[11] Additionally, 11% of players who suffer an HSI experience a recurrence,[12] a rate comparable to the 12–16% observed in men's football.[13] Comparative studies showed that male players are about twice as likely as female players to sustain HSIs, especially during match play.[14] However, as women's football rapidly evolves, elite players now face significantly greater physical demands than in the last decade, particularly in terms of high-speed distance covered and number of sprints.[15] This escalating match play demand may have heightened the susceptibility to muscle-tendon injuries among female footballers.[6 16]

Developing effective injury prevention programmes requires understanding the nature and mechanisms of specific injuries.[17] However, there is currently a significant scientific gender gap in HSI research, with much of the available data

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**HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY**

- ⇒ Future research and practice strategies may benefit from combining hamstring strength training within drills that also replicate the technical and coordinative demands of real injury scenarios. This involves integrating specific situational patterns (run-type and stretch-type), mechanical perturbations (hold-type and push-type contacts) and contextual factors (eg, ball interaction, tactical positioning and decision-making under time constraints) into dynamic and unpredictable training tasks.
- ⇒ In addition to tactical video analysis, footage of typical injury patterns should be integrated into trainer education programmes to help players recognise and navigate high-risk situations for HSIs, considering individual characteristics like playing position.

derived from studies on men.[18] Applying findings from men's to women's football may not translate effectively as sex-based differences in biomechanical properties, hormone profiles and sporting environments can alter injury risks and patterns.[19] To be effective, preventive measures should be sport-specific and consider sex, level of competition and injury profile.[20]

A more precise description of injury-inciting events would be of great help to improve risk mitigation strategies by more accurately targeting the specific injury mechanisms.[21] Video analysis is a commonly adopted technique to describe the injury context and the players' activities around the time of injury,[22] allowing both the biomechanical analysis and the assessment of technical and cognitive demands. In football, video analysis has been used in previous studies to investigate HSI mechanisms (non-contact vs indirect contact) and situational patterns (sprint-related vs stretch-related), as well as joint and trunk kinematics.[23–26] Despite sufficient description of HSIs events in male football, only one comparative video analysis study[27] provided some evidence on HSIs in female players.

Thus, this study aims to fill this gap by investigating the inciting events of HSIs through video analysis, describing the mechanism, situational pattern and biomechanics of the sport-specific activities performed before and at the time of injury.

## METHODS

This study was a descriptive observational video analysis of HSIs in top national and international women's football competitions at both club and national team levels. The competitions were selected based on their FIFA ranking and included a total of 13 club matches from the USA, 8 from Italy, 8 from Spain, 8 from England, 6 from France and 3 from Germany, covering both domestic (n=30) and international (n=6) league and cup (n=10) competitions. Additionally, we analysed 11 matches from national team competitions. Data collection covered seven seasons from 2017/2018 to 2023/2024. The study design used the Quality Appraisal for Sports Injury Video Analysis Studies (QA-SIVAS) scale[28] and the Football Injury Inciting Circumstances Classification System.[29]

### Injury identification and video extraction

The reports of each HSI case were identified through online database searches. Subsequently, the corresponding full-match video was retrieved to confirm and identify the injury event. Player data, including baseline characteristics and injury details, were collected from FBref.com (Sports Reference LLC, Philadelphia, USA) and supplemented with a Google search [name of player AND (hamstring OR semitendinosus OR semimembranosus OR biceps femoris) * AND injury]. It is not uncommon for players experiencing muscular injuries to continue playing and report the incident afterwards; consequently, injuries were included only if the player was forced to leave the pitch and be substituted, ensuring precise identification of the injury frame (IF). Videos were obtained from YouTube and Wyscout platforms. Each video clip included approximately 1 min before and 30 s after the suspected IF.

### Video assessment

Three reviewers with documented experience in video analysis studies—a sports medicine physician, a biomechanics professor and professional UEFA A-licensed coach, and a PhD candidate and sport scientist—evaluated all injury videos in real time, slow motion and frame-by-frame to identify key injury details. Each reviewer independently classified the injury mechanism, situational patterns and biomechanical characteristics, blinded to each other's assessments. Discrepancies were resolved through a consensus meeting with the research team, which also included a former professional women's basketball player with expertise in video analysis and a medical doctor and professor with experience in injury-related research. During this meeting, the videos were critically reviewed again until agreement was reached following established methodologies.[24 26]

A predetermined checklist, developed from existing observation forms, was used to ensure consistent and objective analysis. This checklist included the following categories: (1) anthropometric data; (2) match conditions and characteristics; (3) injury distribution; (4) diagnosis and potential risk factors; (5) injury mechanism; (6) situational pattern and (7) biomechanics. The use of this standardised form ensured consistency and comprehensiveness in the analysis. The software Kinovea (V.0.9.5) was used for video analysis; the number and resolution of camera views were registered.

Two injury mechanism categories were identified[1]: non-contact and[2] indirect contact, defined as an injury resulting from an external force applied to the player, but not directly to the muscle injured. Indirect contact mechanisms were further classified into hold-type and push-type contacts, based on the direction and intent of the applied force. In hold-type contacts, the opponent applies force against the injured player's movement direction, aiming to slow him down or restrict forward motion. In push-type contacts, the force is applied in the same direction as the player's trajectory, often to disrupt balance by accelerating the player unexpectedly. The situational patterns were classified as run-type or stretch-type, based on previous literature.[24] The stretch-type pattern was further divided into duel, kick and other types. The run-type pattern was classified based on the player's velocity profile and movement mechanics from video analysis. Three phases were identified for injury occurrence: acceleration, high-speed and deceleration. The acceleration phase occurs when the player rapidly increases speed in the first few metres (0–10 m) after a standing or jogging start, often exhibiting a forward lean. The high-speed phase refers to the player reaching a high to near-maximal speed, typically associated with high-speed or very-high-speed running and sprinting over longer distances. The deceleration phase begins when the player reduces speed, often in preparation for a change in direction, to avoid a tackle or to stop after a high-velocity action. Kick-type injuries occurred during the preparation, execution


**Figure 1** Examples of kinematic analysis using Kinovea software: (A) Knee angle, (B) hip angle, (C) inter-limb angle and (D) trunk tilt.

or balance recovery phases of a kick, while duel-type injuries involved the attempts to change/maintain possession of the ball. This includes situations where a player presses to steal the ball from an opponent, intercepts to gain control of a contended/dead ball and protects/attacks to retain possession. This situational pattern involves football-specific actions such as lunging, breaking, sliding, shielding, landing and regaining balance. Additional injury context information included duels, ball interactions, number of opponents near the injured player, opposing team, game result, pitch size and surface, home/away/neutral stadium, kick-off time, weather and attendance. When available, diagnostic information (including injury location, level and type) and a history of previous severe lower limb injuries (defined as injuries occurring at the hip, groin, thigh, knee, lower leg, ankle or foot, involving muscles/tendons, ligaments/joint capsules and cartilage/synovium/bursa, with a lay-off of more than 28 days) were collected from official injury reports, in accordance with the football-specific extension of the International Olympic Committee consensus statement.[30]

Joint and trunk kinematics were analysed using videos with at least one clear quasi-sagittal plane view (figure 1). Due to parallax distortion and the limitations of 2D video analysis, angles were reported in ranges of 30°, with flexion as positive and extension as negative values. The kinematic analyses included the hip and knee angles of the injured leg, the inter-limb angle (the angle between the thigh segments in the sagittal plane) and the trunk position (forward, neutral ±10° or backward, with the earth vertical as a reference).

### Seasonal, match and field distribution

Seasonal, match and field distribution were obtained in relation to the injured player's position, including (1) the competition period and month of the injury, (2) the phase of the game (minute and half), (3) the minutes played by the injured athlete, (4) the field location at injury and (5) player's position.

### Patient and public involvement

All the videos we accessed are publicly available, and no personal player information was accessed. Therefore, ethical permission and patient consent for publication were not required. The study's findings are expected to be shared through publicly accessible platforms (newspaper articles, television interviews, podcasts, blogs) to educate the community on how HSIs occur and how this knowledge may inform future prevention strategies.

### Equity, diversity and inclusion statement

We responded to the growing call for more research on women's football players, aiming to bridge the gap in knowledge compared with their male counterparts. Our study included women's professional football players from diverse national championships and teams, all from high-income countries. The authors' team consists of professionals from medicine, sports science and biomechanics, including both female and male researchers from high-income countries, fostering diversity in expertise. This study is an important step in addressing gender imbalances in football research.

### Statistical analysis

Categorical data were presented as absolute and relative frequencies. To compare variable frequency distributions, we used the $\chi^2$ test. The significance threshold was set at $\alpha=0.05$. Effect sizes were computed using Cramer's V ($\varphi c$), with interpretations as follows: $\varphi c=0.00$–0.10 (little to no association), $\varphi c=0.10$–0.30 (weak association), $\varphi c=0.30$–0.50 (moderate association) and $\varphi c=>0.50$ (strong association). Statistical analyses of this study are consistent with the CHecklist for statistical Assessment of Medical Papers (CHAMP statement).[31]

## RESULTS

A total of 109 HSIs were identified as match injuries, with 57 (52%) videos eligible for analysis involving 50 players (seven recurrences). Reasons for exclusion included cases where the video was available but the injury was not captured or the IF was unclear (n=28), where the match reportage was available but no video (n=12), where the video was available but the licence did not cover the competition or league (n=8) and where the match was absent from the WyScout archive (n=4). Of the eligible videos, 3 had four camera views, 7 had three, 24 had two and 23 had one. The camera angles comprised semi-frontal anterior (n=14), semi-frontal posterior (n=26), semi-sagittal right (n=36) and semi-sagittal left (n=26) views. Injuries occurred during national club competitions (n=40), the Champions League (n=6) and national team competitions (n=11). Video resolution (pixels) was 640×360 (n=1), 1280×720 (n=24) and 1920×1080 (n=32). The sampling frequency (frames per second) was 25 (n=12), 30 (n=29), 50 (n=7) and 60 (n=9).

The players (age: 28±4 years; height: 1.68±0.05 m; weight: 60±5 kg; right-footed n=43) were goalkeepers (4%), centre-backs (14%), full-backs (9%), midfielders (28%), wingers (12%) and strikers (33%). The lay-off time was 76±93 days, significantly increased by four surgical cases and one career-ending recurrence. Excluding these, the lay-off was 53±37 days. Injuries were severe (>28 days) in 74% of cases, moderate (8–28 days) in 21% and mild (4–7 days) in 5%. 31 cases (54%) involved the dominant leg (21 right leg). Recurrent HSIs made up 30% (mostly delayed>12 months), and 42% of players had a history of severe lower limb injuries. Injury location was reported in only 23% of cases, with the biceps femoris most affected (12 out of 13). Other diagnostic details, such as injury level and type, were often incomplete.

### Injury mechanism analysis

Of the total injuries, 74% were classified as non-contact ($p<0.001$, $\varphi c=0.47$) and 26% indirect contact (table 1). Among

Table 1 Distribution of injury mechanisms categorised based on a predefined checklist

| Variable | Category | n | % | χ2 | P value | φc |
|---|---|---|---|---|---|---|
| Mechanism | Non-contact | 42 | 74 | 12.789 | <0.001 | 0.47 |
| | Indirect | 15 | 26 | | | |
| Contact | Injured leg | 2 | 13 | 5.2 | 0.074 | 0.21 |
| | Uninjured leg | 4 | 27 | | | |
| | Upper body | 9 | 60 | | | |
| Type of contact | Hit/push | 9 | 60 | 0.6 | 0.439 | 0.10 |
| | Hold/pull | 6 | 40 | | | |
| Opponent(s) | Yes | 41 | 72 | 10.97 | 0.001 | 0.44 |
| | No | 16 | 28 | | | |
| Duel | Yes | 29 | 51 | 0.018 | 0.895 | 0.02 |
| | No | 28 | 49 | | | |
| Ball interaction | Yes | 39 | 68 | 7.737 | 0.005 | 0.37 |
| | No | 18 | 32 | | | |

The table presents the absolute number (n) and percentage of each category, along with $\chi^2$ values, p values and effect size (φc). Contact characteristics include the body region involved and the type of contact. The presence of an opponent, involvement in a duel and ball interaction are also reported.

the indirect contacts, the upper body was the most affected area (60%), followed by the lower body (27% uninjured leg and 13% injured leg). Contact occurred 407±256 ms before the injury. Contact type was classified as hold/pull (40%), where force was applied against the injured player's running direction and hit/push (60%), where force was applied in the same direction (figure 2).

In 72% of cases ($p<0.01$, $\varphi c=0.44$), at least one opponent was within the player's action area (3.14 m²). Among these, 51% involved direct duels, predominantly side-by-side rather than frontal 1 vs 1. Ball interaction was observed in 68% of cases, indicating the injured player was attempting to engage with the ball, with or without direct contact. Further details are provided in table 1.

## Situational pattern and inciting activities

Two main situational patterns were identified for non-contact and indirect contact HSIs: run-type (n=29, 51%) and stretch-type (n=28, 49%). The stretch-type injuries were further divided into kick-type (26%) and duel-type (28%). Additionally, two cases (landing from a wall jump) were categorised as stretch-type but did not fit into the aforementioned subcategories (figure 3).

Injuries occurred more frequently in offensive, compared with defensive situations (72%, $p<0.0001$, $\varphi c=0.44$). Inciting activities are detailed in table 2.

## Run-type

Run-type HSIs, accounting for 51% of all injuries, were analysed in detail (online supplemental tables S2 and S3). Among these, 41% started from a standing position and half while jogging. Curved runs accounted for 52%, while the remainder were linear. Injuries were classified by run phase: acceleration (21%), high-speed (59%) and deceleration (21%). Only seven (24%) occurred in typical running scenarios without ball interaction, opponents or duels. The majority (72%) occurred while attacking, with strikers most affected (34%). The estimated run distance was 19±12 m, with a duration of 2.9±1.8 s and 13±7 steps.

## Kick-type

Most of the kick-type injuries occurred while passing (43%) and crossing/clearing (43%), and 14% while shooting. Injuries occurred while attacking in 79% of the cases, with midfielders most affected (43%). No injuries were reported during free kicks, corner kicks or other dead-ball situations; all occurred with the ball in motion. One case involved a goalkeeper's punt kick. Kick-type injuries were evenly split between the loading (43%) and the kicking leg (57%) (see online supplemental table S4).

## Duel-type

43% of these injuries occurred during ball interceptions, 29% while pressing and 14% while protecting possession. This pattern showed a high incidence of duels (83%), with 58% involving indirect contact. Strikers were most affected (58%). Injuries involved the dominant leg in 83% of cases and occurred in a closed kinetic chain scenario in 75%. Most injuries (83%) occurred while decelerating rather than accelerating (see details in online supplemental table S5).

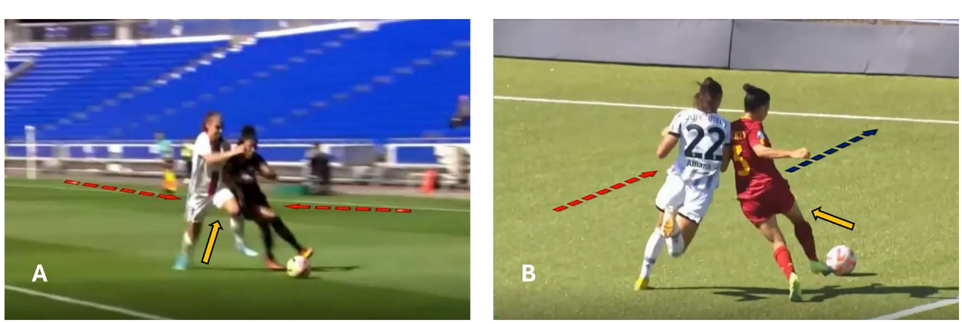


**Figure 2** Examples of the two common mechanical perturbations observed in indirect contact cases: (A) hold/pull and (B) hit/push. The yellow arrow indicates the injured leg in the subsequent frames.

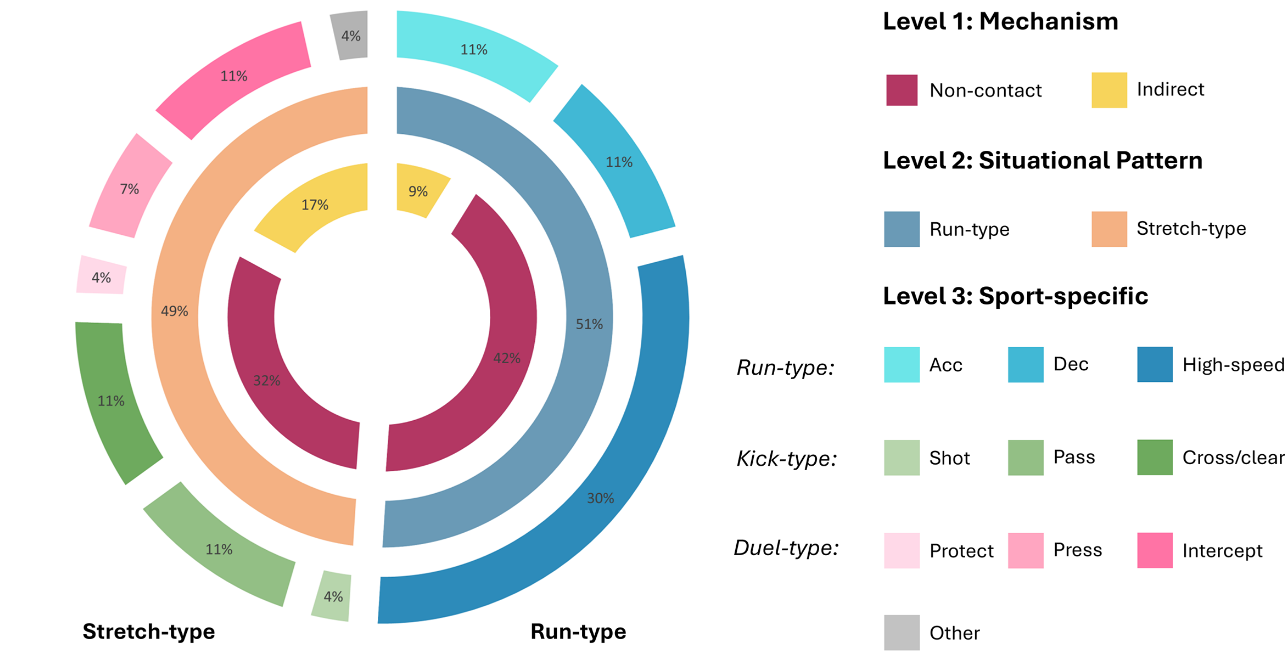


**Figure 3** Classification of hamstring injury mechanisms (level 1, inner circle), situational patterns (level 2, middle circle) and sport-specific for football (level 3, outer circle).

## Joint and trunk kinematics

Biomechanical analysis was available for 39 videos (excluding 14 run-type, 2 kick-type and 2 wall jump cases; see online supplemental table S6). For knee joint movement, a specific injury pattern was observed in most cases, involving knee extension (59%) at an angle of less than 30° at the IF. The hip joint was frequently (39%) involved in flexion. For inter-limb angle detection (n=26), the range was typically between 60° and 90°. Trunk position was recorded as flexion in 16 cases, neutral in 18 cases and extension in 5 cases. Hip extension (0–30°) was primarily observed in run-type injuries (7/8), while other patterns mostly involved hip flexion. The trunk was mostly neutral but showed extension and flexion roles in kicking injuries.

## Seasonal match and pitch injury distribution

March had the highest injury incidence (25%). Injuries were most common during the second (16′−30′, 28%) and fifth (61′−75′, 21%) match periods (online supplemental figures S1 and S2). Nearly half of the injuries occurred in the offensive third of the pitch (goal area and left corridor), one-third in the midfield zone and the remainder in the defensive third (figure 4).

## DISCUSSION

The key finding of this study was that HSIs in elite women's football primarily followed run-type and stretch-type situational patterns.[23 24 26] These patterns often involve rapid movements with high eccentric demands on the posterior thigh along with hip flexion and knee extension. Both injury types are strains, with stretch-type occurring at long muscle lengths, while run-type occurs within the muscle's normal working range.[32] In addition to situational patterns, external factors such as ball interaction, opponent pressure, physical contact and space constraints force players to rapidly adapt movements, increasing injury risk.

## Injury context

Only 52% of the injury videos were eligible for analysis, meaning this study represents a subsection of HSIs in women's football match play. The player substitution criterion likely skewed the sample towards more acute onset and severe injuries, potentially under-representing less severe cases, as reflected in the high injury severity observed. While this represents an inherent limitation of observational studies, it warrants consideration when interpreting the findings. It is important to note that video analysis studies aim to describe injury mechanisms and situational patterns, rather than providing a complete epidemiological overview. This focus is especially relevant for HSIs, where players can often complete the game despite the injury, unlike ligament or tendon injuries which typically force players to stop immediately. Additionally, the limited media coverage of women's football may result in more attention being paid to severe injuries, which are more likely to be reported, potentially contributing to a selection bias that affects the representation of injury severity. HSIs were more common in offensive situations (72%), whereas the opposite trend was observed for anterior cruciate ligaments (ACL) ruptures.[33 34] Most injuries in this study occurred during the middle quarter of both halves. The timing of ACL injuries is often linked to higher-intensity demands or early onset of fatigue, which can impair neuromuscular control and decision-making.[35] Similarly, HSIs are suggested to be preceded by a short period of higher running demands in professional football players.[36] This suggests that the mechanisms underlying injuries are often more complex than a single triggering event, indicating non-linear causality. Injuries may result from the dynamic interaction of multiple factors that evolve across different timescales.[2] This complexity arises from the interplay between intrinsic factors, such as fatigue and pre-existing conditions, and extrinsic factors, including environmental and contextual conditions (see online supplemental table S1), which may increase the probability that a movement typically considered safe becomes more likely to result in injury. Future video analysis studies should include a control group with comparable situations and/or biomechanics not resulting in injury (item 10 of the QA-SIVAS scale) to better establish causal relationships and mitigate misinterpretation of findings.

Table 2 Situational patterns and inciting activities performed at the injury frame

| Variable | Category | n | % | χ2 | P value | φc |
|---|---|---|---|---|---|---|
| Situational pattern | Run-type | 29 | 51 | 0.018 | 0.895 | 0.02 |
| | Stretch-type | 28 | 49 | | | |
| Football-specific | Run | 29 | 51 | 26.158 | <0.0001 | 0.39 |
| | Kick | 14 | 25 | | | |
| | Duel | 12 | 21 | | | |
| | Other | 2 | 4 | | | |
| Playing phase | Attack | 41 | 72 | 10.965 | <0.0001 | 0.44 |
| | Defend | 16 | 28 | | | |
| Kinetic chain | Open | 15 | 26 | 3.895 | 0.143 | 0.18 |
| | Closed | 26 | 46 | | | |
| | Unsure | 16 | 28 | | | |
| Loading leg | Injured | 24 | 42 | 30.632 | <0.0001 | 0.37 |
| | Uninjured | 11 | 19 | | | |
| | None | 3 | 5 | | | |
| | Both | 2 | 4 | | | |
| | Unsure | 17 | 30 | | | |
| Foot strike | Fore | 6 | 23 | 5.385 | 0.145 | 0.26 |
| | Mid | 8 | 31 | | | |
| | Heel | 10 | 38 | | | |
| | N/A | 2 | 8 | | | |
| Horizontal speed | Very low | 4 | 7 | 19 | <0.001 | 0.33 |
| | Low | 19 | 33 | | | |
| | Moderate | 25 | 44 | | | |
| | High | 9 | 16 | | | |
| Vertical speed | Very low | 18 | 32 | 47.772 | <0.001 | 0.53 |
| | Low | 34 | 60 | | | |
| | Moderate | 3 | 5 | | | |
| | High | 2 | 4 | | | |
| Phase | Acceleration | 32 | 56 | 0.86 | 0.354 | 0.12 |
| | Deceleration | 25 | 44 | | | |

The table details the playing phase and biomechanical variables such as kinetic chain, loading leg, foot strike pattern and speed (horizontal and vertical). Absolute numbers (n), percentages, $\chi^2$ values, p values and effect size (φc) are reported for each variable.

## Injury mechanisms

All injuries were classified as either non-contact (74%) or indirect contact (26%). These results align with Gronwald *et al* findings on professional male soccer,[24] but the proportion of indirect contact injuries doubled that reported by Della Villa *et al*.[26] Indirect contact injuries, primarily associated with upper body perturbations, were twice as likely to involve stretch-type compared with run-type injuries. These contacts were categorised into hold/pull and hit/push types as players must manage distinct perturbations that challenge their biomechanical strategies. In hold/pull contacts, sudden deceleration potentially increases the eccentric load on lower limbs as they counteract the force and maintain balance.[37] This effect is further intensified by trunk tilt, which puts additional stress on the posterior muscle chain.[38] In hit/push situations, an acceleration force increases the injured player's velocity, shifting the centre-of-mass forward and likely reducing the time to stabilise joints before ground contact.[39] Hold-type/pull-type contacts seemed to be associated with greater injury severity (122±104 days) compared with hit-type/push-type contacts (73±71 days), suggesting that different types of perturbation may influence not only injury risk but also its nature and in turn recovery time. Further research is warranted to better understand the relationship between perturbation type and injury severity. Contact in football can involve multiple areas (upper and lower body), multiple players, can be prolonged (eg, shirt pulling) and vary in intensity. Our analysis suggests that midfielders, especially when interacting with the ball, are at higher risk of indirect contacts and should receive targeted training. Given that most indirect contacts (60%) occur at the upper body level, these interactions likely increased trunk

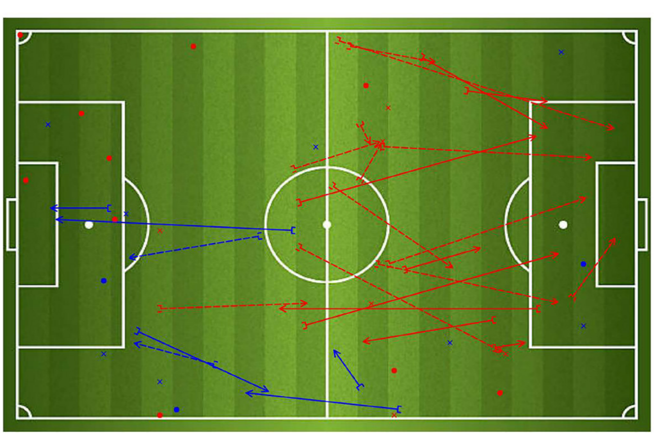

**Figure 4** Injury pitch distribution. Red: offensive phase injury. Blue: defensive phase injury. The continuous line indicates the linear sprints and the dashed line the curved sprints. Circles represent the kick-type, crosses the duel-type and triangles the other-type injuries.

perturbations and, consequently, influenced pelvic stability. The biarticular nature of hamstring muscles and its myofascial connection to the erector spinae via the sacrotuberous ligament emphasise the pelvis's role in hamstring strain regulation.[40] For instance, increased anterior pelvic tilt has been shown to lead to a significant, non-uniform increase in tissue elongation across all regions of the hamstrings, with greater elongation in the proximal region.[41] Athletes with a history of HSI often show reduced neuromuscular coordination of the lumbopelvic muscles when responding to unanticipated trunk movements.[42] Perturbation training has been shown to improve neuromuscular control and reduce the risk of ACL injuries, particularly in female athletes with quadriceps dominance deficits, by enhancing hamstring activation and knee flexion angles.[43] Given the importance of neuromuscular coordination in injury prevention, video analysis could serve as a valuable feedback tool for enhancing movement efficiency and technique refinement. Commonly used in football for tactical preparation, video analysis could similarly help athletes identify and correct technique flaws and behaviours, potentially reducing injury risk while optimising performance.[44]

## Situational pattern

HSIs were equally distributed between run and stretch-types (see figure 3). All stretch-type injuries (excluding two landings from a wall jump) involved an interaction with the ball. Stretch-type injuries often occurred with excessive hamstring lengthening, with the hip flexed and the knee extended. Most kick-type injuries occurred during passing and crossing rather than shooting. Nearly half of the cases (43%) involved the loading leg, suggesting that rotational forces, extreme range-of-motion in unusual positions and anticipation movements influence HSIs more than peak force alone.[45] However, 2D video analysis, due to its intrinsic limitations, does not allow for such detailed analysis. There is ongoing debate about whether run-type injuries occur during the early stance or swing phase of running.[46] Based on our visual inspection of joint kinematics on the sagittal plane, the rapid transition from knee flexion to extension in the middle swing phase could also be critical, particularly when combined with overstriding. Most run-type injuries occurred at high speeds, but about 40% during acceleration or deceleration. The distance covered during these runs was 19±12 m. This highlights the need to incorporate match demands into sprint training, such as linear and curved progressions, varied run lengths, ball interactions, opponent engagement and cognitive demands (eg, decision-making). Moreover, skilled footballers often manipulate their opponents' perceptions by, for example, hiding their true intentions (eg, feints) through motor inhibition.[47] These training features should be tailored to individual players' positions, characteristics and team tactics.

An important aspect of designing effective injury prevention programmes is the identification, analysis and replication of influential risk factors and sport-specific movements, beyond just sprinting, recognised as high-risk situations. Without this comprehensive approach, prevention efforts may remain incomplete, leaving players more vulnerable. In addition to improving hamstring flexibility and strength, training strategies should emphasise technique, coordination, balance and control—key skills for efficient movement execution that ensure both movement quantity and quality. This is particularly relevant in football, where the lower limbs play a dual role in both locomotion and ball-handling demands,[48] a distinction that sets this sport apart from all others. This unique characteristic may partly explain why football is the sport with the highest incidence of HSIs.

## Clinical implications

Understanding the situational patterns and biomechanical characteristics of HSIs provides evidence-based information for developing targeted injury risk reduction strategies.[22] Injury prevention programmes may improve by targeting sport-specific injury patterns, including running, kicking and duelling. Incorporating varied exercises and real on-field scenarios into training can better prepare the hamstring muscles for game demands, potentially reducing the risk of injury. While there is growing evidence supporting the role of targeted training in injury prevention, the causal relationship between targeting specific injury mechanisms and reducing injury incidence remains an area of ongoing investigation, and further studies are required to definitively establish this link.

## Limitations

Limited footage in women's football due to reduced media coverage made tracking injuries challenging. To collect enough cases, the study covered seven seasons across six different championships, which hinders findings generalisation. Differences in playing style, fitness level, match frequency, climate, together with other factors, may influence injury patterns and mechanisms. An official injury video database would enhance research in this field by overcoming limitations such as small sample sizes and time-consuming searches, providing more reliable results and supporting future data-driven applications. A major limitation in video-based analysis of HSIs is the challenge in identifying the precise IF, which is less clear than in ACL ruptures or tendon injuries. This is especially problematic in 'run' and 'open kinetic chain stretch' patterns, where injury mechanisms involve rapid, complex movements that make it difficult to isolate the exact moment of injury onset. To enhance the accuracy of identifying the IF, incorporating athletes' own narratives of their injury experiences could provide valuable insights. For instance, using questionnaires or interviews to gather players' accounts of their movements, symptoms and perceptions at the time of injury could help corroborate or refine video-based observations. The injured location was often recorded generically as 'hamstring', with only 23% specifying the exact muscle involved. Further details on injury level and type were usually unavailable, and no MRI was collected. Enhanced diagnostic precision in future studies could support analysis of potential associations between situational patterns and injury types as existing evidence suggests that biceps femoris long head is frequently linked to run-type HSI, while semitendinosus and semimembranosus are more common in stretch-type patterns.[49,50] The absence of match play and exposure data further limited the study. Addressing these limitations in future research may contribute to a deeper understanding of the situational and biomechanical factors underlying distinct HSI types.

## CONCLUSION

This study analysed 57 HSIs in elite women's football, revealing that HSIs primarily followed run-type and stretch-type patterns, with non-contact mechanisms being the most common. However, a subset of injuries involved indirect contact mechanisms, such as push or pull perturbations from an opponent, which may have contributed to the loss of balance or altered movement execution preceding injury, particularly in the duel-type subcategory. HSIs often took place during offensive play, particularly while sprinting or engaging in ball-related actions, with additional factors such as opponent pressure and cognitive demand influencing the injury risk. Our findings highlight the importance of replicating match conditions in injury prevention programmes, incorporating varied sprint distances, ball interactions and opponents' influence to prepare players for the dynamic and changing circumstances identified in HSI scenarios.

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