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Original research

Do non-contact injuries occur during high-speed running in elite football? Preliminary results from a novel GPS and video-based method

Francesco Aiello [a,b], Christian Di Claudio [c], Maurizio Fanchini [c,d], Franco M. Impellizzeri [e], Alan McCall [a,b], Carwyn Sharp [c], Susan J. Brown [b,*]

[a] Arsenal Performance and Research Team, Arsenal Football Club, UK
[b] School of Applied Sciences, Edinburgh Napier University, UK
[c] AS Roma Football Club, Roma, Italy
[d] University of Verona, Italy
[e] Faculty of Health, Sport and Exercise Discipline Group, University of Technology Sydney, Australia

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ABSTRACT

Objectives: Understanding how injuries occur (inciting circumstances) is useful for developing etiological hypotheses and prevention strategies. The aims of this study were 1) to evaluate the feasibility of a method combining video and Global Positioning System data to estimate the speed and acceleration of activities leading to injuries and 2) to use this method to analyse the inciting circumstances leading to non-contact injuries.
Design: Retrospective descriptive study.
Methods: Injury inciting circumstances from 46 elite players over three seasons were analysed from video recordings and from external load measures collected through Catapult Vector S7 Global Positioning System.
Results: In total 34 non-contact injuries were analysed. Sixteen out of the seventeen hamstring injuries occurred when players were running for (median and interquartile range) 16.75 m (8.42–26.65 m) and achieved a peak speed of 29.28 $km \cdot h^{-1}$ (26.61–31.13 $km \cdot h^{-1}$) which corresponded to 87.55 % of players' maximal speed (78.5 %–89.75 %). Of the three adductor injuries, one occurred whilst the player was decelerating without the ball, one occurred whilst the player was accelerating and controlling the ball at knee level, and one occurred whilst the player was performing an instep kick. Two quadriceps injuries occurred whilst the players were kicking either whilst walking or running.
Conclusions: From the preliminary results reported in this study most hamstring injuries occurred when players ran > 25 $km \cdot h^{-1}$ and above 80 % of their maximal speed. This study suggests that this novel approach can allow a detailed and standardised analysis of injury inciting circumstances.

Practical implications

- Despite some challenges, the method proposed in this study is usable to provide detailed information on the activities performed at the time of injury such as running speed and technical actions.
- Limiting players' exposure to maximal running speed (as sometimes suggested in the literature) may not be a good strategy to reduce injury risk since injuries seem to occur prevalently at high speeds (>25 $km \cdot h^{-1}$, >70 % maximal speed). Limiting exposure to high speeds may not be advisable since this could constitute a suboptimal training stimulus.
- Information on the activities performed at the time of injury can help hypothesise injury mechanisms and activities that expose players to a high risk of injury.

1. Introduction

The overall incidence of injury in male football equals to 8.1 injuries/1000 hours,[1] which can negatively impact players' health and the club's finances.[2,3] Understanding how injuries occur is useful to support the development of etiological hypotheses and prevention strategies that can be experimentally tested.[4] As a consequence, numerous studies have analysed the circumstances which lead to injury (i.e., inciting circumstances).[5] However, a recent systematic review reported that the current literature is difficult to interpret because the inciting circumstances have been reported using arbitrary classification systems.[5] Additionally, injuries were commonly

* Corresponding author.
E-mail address: su.brown@napier.ac.uk (S.J. Brown).

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reported to occur whilst running, accelerating, or running at high speed, without any specific indication of range of speeds or accelerations. A more precise understanding of the running speeds when injuries occurred can help to 1) hypothesise potential mechanisms of injury to test in further studies, 2) identify higher risk activities, and 3) provide information that can guide the development of prevention strategies, training programmes, rehabilitation and return to play protocols, for example informing practitioners on which running speeds they need to prepare their athletes to or at what speeds the risk of injury is present.[6,7] Nowadays, players' locomotor activity is monitored using systems such as the Global Positioning System (GPS) and video-analysis. However, to the best of our knowledge these data have never been used to analyse the specific activity performed at the time of injury, although other studies have evaluated the period around injury occurrence.[8,9] Therefore, the aims of this study were 1) to evaluate the feasibility of a method developed by Aiello et al.[10] combining video and GPS data to estimate the speeds and accelerations when non-contact injuries occur and 2) to use this method to provide preliminary information about the speed and acceleration at which non-contact injuries occur in elite football players.

2. Methods

2.1. Participants

A retrospective descriptive study was conducted using data collected from 46 male elite players (mean ± SD, age 26.6 ± 4.3 years, height 185 ± 6.6 cm, weight 80.8 ± 6.3 kg) from one Serie A football club over three seasons (Table S1). Ethical approval was granted from Edinburgh Napier University Research Integrity Committee (SAS/2786536).

2.2. Data collection

External load measures were routinely collected by the club during all training sessions and matches through Catapult Vector S7 GPS (Catapult Sports, Melbourne, Australia) which is reported to have good inter-device reliability for the measurement of peak speed and average acceleration,[11–13] and is certified by FIFA for use both in training and matches.[14] Each unit included a 100-Hz accelerometer, magnetometer, gyroscope and 10 Hz GPS. Raw data were exported and analysed with OpenField 3.4.0 (Catapult Sports, Melbourne, Australia). GPS units were turned on one hour before the session and the same units were worn by the same players during the study. During the sessions in which injuries occurred the average number of satellites connected to each device ranged between 8 and 17 (median number of satellites = 14, IQR = 13–15) and the average horizontal dilution of precision ranged between 0.7 and 1.6 (median = 1, IQR = 0.8–1).

Training sessions were routinely recorded by the video analysis department and viewed using the club's internal database. During training sessions, the recordings were acquired through a fixed-camera system (AXIS P1448-LE, Network, Spideo system, Malmo, Sweden) placed 6 m from the lateral line at a height of 18 m, whilst during matches the video was acquired from TV broadcasting services. Injuries were diagnosed by the team's doctor and medical data were routinely collected by the sports medicine department.

2.3. Definitions

Time-loss injuries were defined as “players' inability to complete or take full part in a football match or training”.[15] Only sudden-onset non-contact injuries were included in the analysis. Speed was defined as the linear distance covered by the players in a given time and is reported in $km \cdot h^{-1}$, whilst acceleration data are reported in $m \cdot s^{-2}$.

2.4. Analysis of inciting circumstances

Injuries were identified on video and analysed by two authors (FA and CDC). Being a retrospective study, it was not possible to interview the players immediately after the injury to understand the exact time of injury occurrence, therefore players were not asked to review the video. However, if injuries were recorded as acute but the inciting event could not be identified on video, a member of staff talked with the player that suffered the injury to request additional information on when the injury occurred. If the player could recall a specific inciting event (i.e., sudden onset injury), that case was included in the analysis, whilst if the player could not identify an inciting event (i.e., gradual onset injury), the case was excluded since only sudden-onset non-contact injuries were included in the analysis. Inciting circumstances were analysed using the Football Injury Inciting Circumstances Classification System (FIICCS) developed by Aiello et al.[10] Therefore, if running injuries occurred during the acceleration phases we estimated they occurred when players achieved peak speed (Fig. S1) and the distance was estimated from the beginning of the acceleration to the peak speed (i.e., T1). If injuries occurred during deceleration, we estimated they occurred when players achieved the peak deceleration (Fig. S2) and the distance from the peak speed to the lowest speed was reported. Peak speed and lowest speed were identified by visual inspection by the same authors with any disagreement resolved by a third author (MF). The inciting circumstances (e.g., the run during which injuries occurred) lasted less than two seconds and because the software did not allow acceleration data to be extracted from such short time periods, average acceleration data were calculated manually using the mean acceleration or deceleration as follows:

$$\Delta v / \Delta t$$

with Δt being the time elapsed between the start and end of the running activity and Δv being the speed difference between the start and end of the activity. Peak speed values are omitted for activities such as walking, jumping, and falling because it was believed not to be relevant for such activities.

2.5. Statistical analysis

Data reported in tables and figures include injuries which occurred during all activities and will be described as median and interquartile range (IQR).

3. Results

In total 34 non-contact injuries were analysed whilst the remaining 34 non-contact injuries (total injuries = 68) could not be analysed due to missing data (Fig. S3, Table S2 Number of injuries identified by injury details). All the injuries analysed were index injuries although some player sustained more than one injury to different body locations during the study. The analysis of the inciting circumstance of each injury required between two and five minutes.

Fifteen out of seventeen hamstring injuries (88 %) analysed occurred whilst players were performing a linear run, one occurred whilst the player was performing a curved run and one whilst the player was controlling the ball in the air after a jump (Table 1). Twelve out of seventeen hamstring injuries (71 %) occurred when the players did not have the ball, whilst the remaining five injuries players were either receiving the ball (n = 3, 18 %) or running with the ball (n = 2, 11 %). Considering only injuries which occurred during running activities, the median distance covered prior to the injury was 16.75 m (8.42–26.65 m) (Fig. 1), with a median peak speed of 29.28 $km \cdot h^{-1}$ (26.61–31.13 $km \cdot h^{-1}$) corresponding to 87.55 % of players' maximal speed (78.50–89.75 %) (Fig. S4). All 17 hamstring running injuries occurred with the players achieving a

Table 1
Summary of physical activity and ball situation at the time of injury.

Location	Physical activity	Injured player without ball	Receiving ball	Running with ball	Kicking	Heading
Hamstring	Accelerating	2 (12 %)	1 (6 %)	0	0	0
	Decelerating	3 (18 %)	1 (6 %)	0	0	0
	Running at steady speed	7 (41 %)	0	2 (12 %)	0	0
	Jumping – in air	0	1 (6 %)	0	0	0
Quadriceps	Running at steady speed	0	0	0	1 (50 %)	0
	Walking	0	0	0	1 (50 %)	0
Adductor	Accelerating	0	1 (17 %)	0	0	0
	Decelerating	1 (17 %)	0	0	0	0
	Running at steady speed	0	1 (17 %)	1 (17 %)	1 (17 %)	0
	Static	0	0	0	1 (17 %)	0
Calf	Accelerating	1 (25 %)	0	0	0	0
	Decelerating	0	0	0	1 (25 %)	0
	Upon landing from jump	0	0	0	0	1 (25 %)
	Walking	0	1 (25 %)	0	0	0
Meniscus	Running at steady speed	1 (100 %)	0	0	0	0
Foot	Running at steady speed	0	0	1 (100 %)	0	0
Knee	Running at steady speed	1 (100 %)	0	0	0	0
LCL	Running at steady speed	0	1 (100 %)	0	0	0
ACL	Changing direction	0	0	1 (100 %)	0	0

peak speed >25 km·h^{-1}. Players decelerated at >-2 m·s^{-2} in four cases, and <-2 m·s^{-2} in one case (median deceleration: 2.41 m·s^{-2}, IQR 2.44–2.07 m·s^{-2}). Players accelerated <2 m·s^{-2} in eight cases and >2 m·s^{-2} in three cases (median acceleration: 1.74 m·s^{-2}, IQR 1.51–2.07 m·s^{-2}) (Fig. 2). Considering only hamstring injuries which occurred whilst players were accelerating (both below and above 2 m·s^{-2}), players ran for 23.9 m (16.75–35.5 m) and achieved a peak speed of 27.6 km·h^{-1} (25.66–31.4 km·h^{-1}) which corresponded to 83 % of their maximal speed (74–91 %). Considering only hamstring injuries which occurred whilst players were decelerating (both below and above 2 m·s^{-2}), players ran for 7.7 m (6–8.2 m) and were decelerating from 30.69 km·h^{-1} (30.27–30.83 km·h^{-1}) which corresponded to 88 % of their maximal speed (87–89 %).

Both quadriceps injuries occurred whilst players were kicking. In one case the player was kicking the ball whilst walking, and in the other the player was kicking the ball whilst running (total distance covered: 9.3 m, acceleration: 1.3 m·s^{-2}, peak speed achieved: 18.71 km·h^{-1} corresponding to 59 % of the player's maximal speed).

Three out of six adductor injuries (50 %) occurred whilst players were running at steady speed and receiving the ball at upper body level (n = 1, 17 %), running with the ball and dribbling past an opponent (n = 1, 17 %), or performing an instep kick (n = 1, 17 %). One adductor injury (17 %) occurred whilst the player was decelerating without the ball, one (17 %) injury occurred whilst the player was accelerating and controlling the ball at knee level, and one (17 %) injury occurred whilst the player performed an instep kick without running. Considering only the injuries which occurred during running activities, players covered an average distance of 8 m (6.1–11.9. m) and achieved a peak speed of 21.39 km·h^{-1} (19.75–21.98 km·h^{-1}), corresponding to 66 % of players' maximal speed (55 %–69 %). In two cases players were decelerating (2.39 and 1.25 m·s^{-2}) and in three cases players were accelerating (1.53, 1.97, 2.80 m·s^{-2}). Considering the three injuries which occurred whilst players were accelerating, players ran for 8.0, 11.0, and 13.1 m and achieved a peak speed of 21.39, 18.25, and 19.75 km·h^{-1} which corresponded to 66 %, 52 % and 55 % of their maximal speed respectively. Considering the two injuries which occurred whilst players

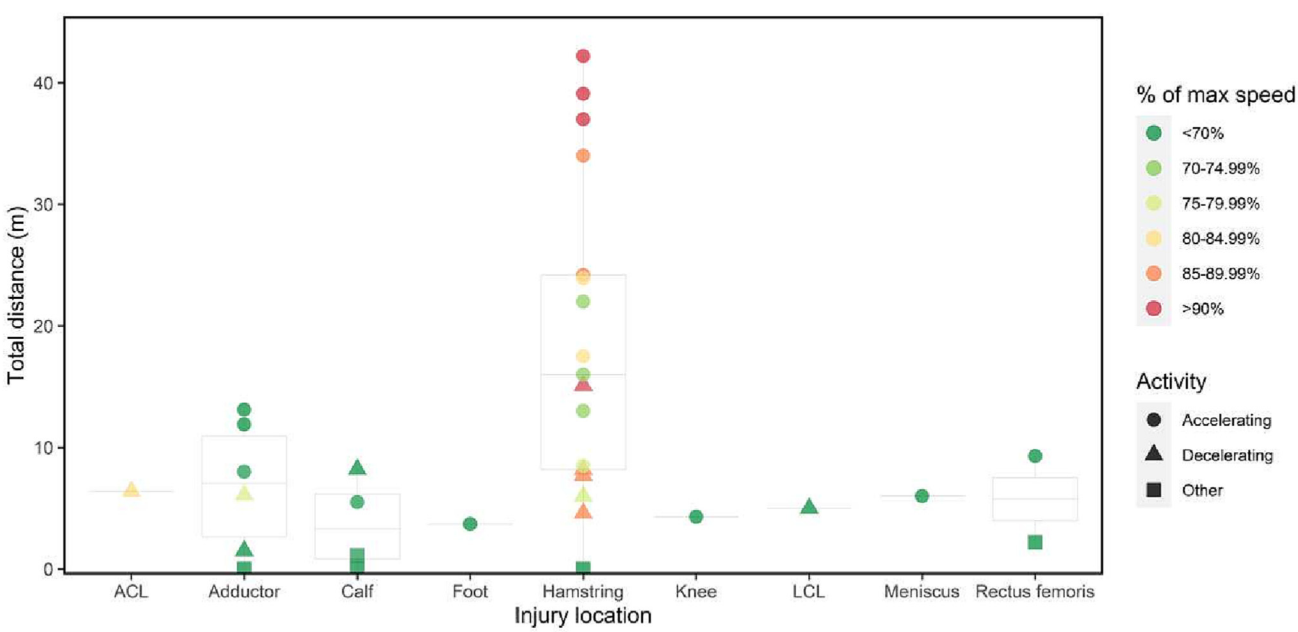

Fig. 1. Distance covered during the inciting activity by injury location and players' activities. Accelerating and decelerating include actions both above and below 2 m·s^{-2}.

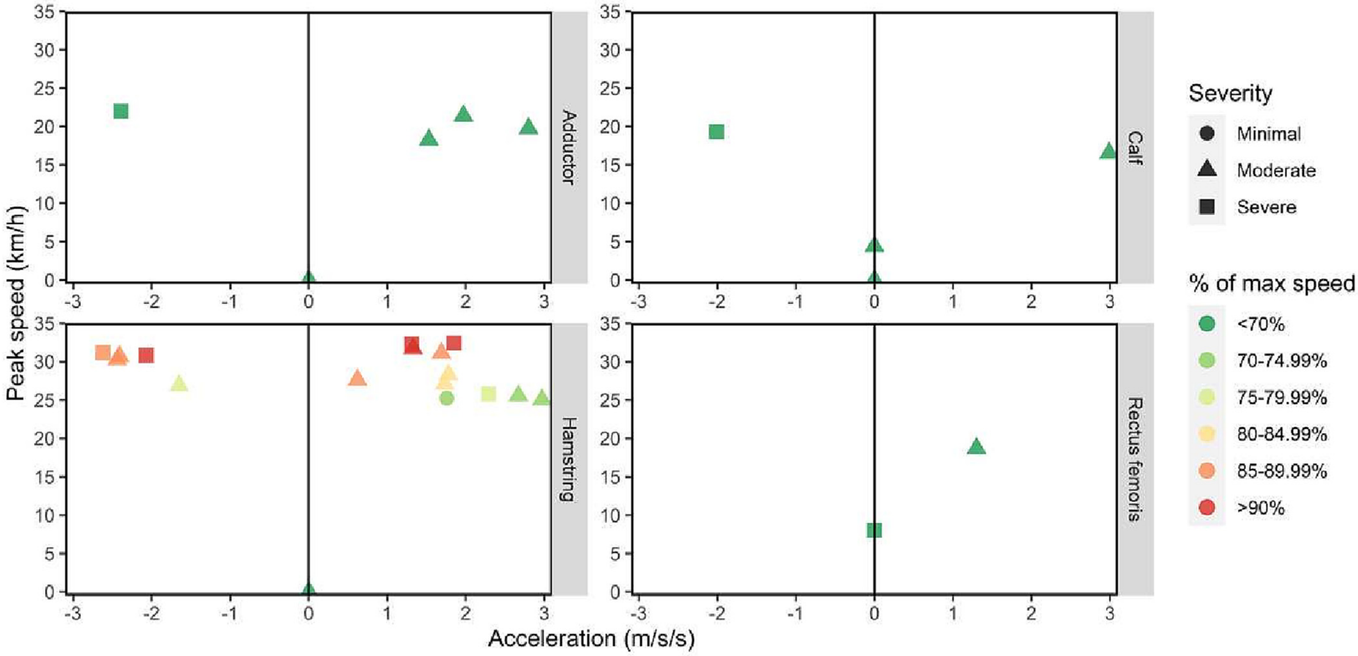

Fig. 2. Peak acceleration and peak speed achieved during the inciting activity of muscle injuries by injury location. When acceleration is positive the peak speed corresponds to the maximal speed achieved by the player during that activity, and when acceleration is negative the peak speed corresponds to the speed from which the player was decelerating. Injuries reported with speed = 0 occurred whilst the player was static or jumping.

were decelerating, players ran for 1.5 and 6.1 m and were decelerating from 21.98 and 24.88 $km \cdot h^{-1}$ which corresponded to 69 % and 77 % of their maximal speed.

A total of four calf injuries were analysed, with one occurring whilst players were accelerating without the ball (acceleration: 2.99 $m \cdot s^{-2}$, distance covered: 5.5 m, peak speed achieved: 16.54 $km \cdot h^{-1}$, 46 % of player's maximal speed) and one decelerating whilst kicking the ball (deceleration: 2.1 $m \cdot s^{-2}$, distance covered: 8.2 m, peak speed achieved: 19.29, 58 % of player's maximal speed). One injury occurred whilst the player was landing after a jump to head the ball and one injury occurred whilst the player was walking and receiving the ball.

Out of all the 34 injuries analysed, 33 (97 %) injuries occurred to players who had played from the beginning of the match or training. The number of hamstring injuries increased over time with the exception of the last period (Fig. S5). Analysis for other injuries was not possible due to the limited number of cases. Fifteen (44 %) injuries occurred during training or home matches and 19 (56 %) injuries occurred during away matches. Six out of the 34 analysed injuries (18 %) occurred during training and 28 (82 %) occurred during matches. With reference to the 28 match injuries, 10 (36 %) injuries occurred whilst the team was winning, five (18 %) whilst the team was losing, and 13 (46 %) whilst the score was tied. Considering injuries which occurred during matches or small sided games, 15 (45 %) injuries occurred during the defensive phase and 18 (55 %) injuries occurred during the offensive phase. Details of injury circumstances for each injury are reported in Table S3.

4. Discussion

This study aimed to develop and test a novel approach to analysing injury inciting circumstances in football and to implement it retrospectively to analyse data collected in one elite football club over three seasons.

The majority (16/17) of hamstring injuries analysed occurred whilst the players were accelerating up to or decelerating from a speed of > 25 $km \cdot h^{-1}$, which is reported in football as high-speed running, very high-speed running, or sprinting.[16] Five injuries occurred at speeds between 70 and 80 %, seven injuries occurred at speeds between 80 and 90 %, and four injuries occurred at speeds above 90 % of players' individual maximal running speed. This could be linked to the higher hamstring activation recorded at high speed.[17,18] Furthermore, players were decelerating > 2 $m \cdot s^{-2}$ in four cases and < 2 $m \cdot s^{-2}$ in one case, and were accelerating < 2 $m \cdot s^{-2}$ in eight cases and > 2 $m \cdot s^{-2}$ in three cases. Therefore, it seems important to prepare players to withstand running at and decelerating from high speeds (i.e., > 25 $km \cdot h^{-1}$ and > 80 % of their maximal running speed).

In elite football, the strategies most frequently used to decrease hamstring injury risk include exposing players to high-speed running and eccentric exercises,[7] although there is limited evidence supporting their effectiveness.[19] The only hamstring injury which did not occur during running activities occurred whilst the player was receiving the ball with the foot at upper body height. All the hamstring injuries analysed occurred whilst players were in a position of hip flexion and knee extension, which supports the available literature on the mechanisms of hamstring injuries.[20] There is debate on whether hamstring injuries that occur during a running activity happen during the late swing (high eccentric work combined with greater musculotendon length) or the early stance (high eccentric work due to ground reaction forces) phase of the running cycle.[21,22] It was not possible to investigate this aspect in the current study, but it may be possible to do so by combining player interviews and prospective video analysis as previously proposed by Serner et al.[23] who reviewed the video with the players shortly after the injuries occurred to identify the time of injury. By combining the approach presented in this study and the one proposed by Serner et al.,[23] it may be possible to analyse the inciting circumstances in greater detail and with greater accuracy. This applies not only to the analysis of the running phase, but also to other aspects such as the running speed and kicking phase. However, given that these activities occur at very high speeds, it's unclear whether players would be able to identify the exact time of injury (e.g., injury occurred during late swing or early stance).

The two quadriceps injuries analysed occurred whilst players were kicking either during walking or running. It was not possible to evaluate the phase of kick during which the injury occurred, but since both injuries occurred to the kicking leg and muscle injuries tend to occur during eccentric actions,[24] it may be that quadriceps injuries occur during the swing phase of kicking, but this needs to be further investigated. In one case the player was kicking whilst walking, whilst in the other the player was running at 18.71 $km \cdot h^{-1}$. It is difficult to say whether one situation may be riskier than the other and to the best of our knowledge the biomechanics of kicking from different walking and running speeds has never been investigated.

The adductor injuries analysed occurred whilst running during acceleration, deceleration and kicking. The observed inciting activities for adductor injuries are similar to the ones reported by Serner et al.[23] which to the best of our knowledge is the only research that has used a similar methodology to our study. The authors reported kicking as a high-risk activity, which is somewhat confirmed by our results. The adductor longus achieves its peak activation and stretch immediately before the kicking leg achieves peak hip extension during the swing phase.[25] However, Serner et al.[23] reported changing direction, reaching, and jumping as other high-risk activities, which is fairly different from our results. It is possible that the inciting activity "receiving the ball" was reported by Serner et al.[23] as "reaching for the ball". In this study two adductor injuries occurred whilst the players were receiving the ball at knee and upper body heights with the injured leg whilst running at high speed. This supports the hypothesis that the adductors are at risk of injury during rapid transitions from hip extension to hip flexion. Serner et al.[23] reported changing direction as the most prevalent inciting activity of adductor injuries, whilst in our study no injuries occurred during changes of direction and only one injury occurred whilst performing a high-intensity deceleration. In our study, adductor injuries occurred in two cases when players were decelerating and in three cases when players were accelerating. Muscle injuries usually occur during eccentric actions,[26] therefore it is plausible that adductor injuries occur during decelerations and changes of direction, as both activities require high eccentric actions.[27] It might be that in the study conducted by Serner et al.[23] the injuries occurred during the deceleration phase of the change of direction, however given that the ground contact time during changes of direction lasts less than 0.5 seconds[28] this may be difficult to evaluate.

Three of the four calf injuries analysed occurred during acceleration, deceleration, and landing activities, which have been reported to be frequent inciting activities in other football codes.[29]

Since only one case was recorded for other injuries (e.g., ACL, LCL, foot) it is difficult to compare data obtained from the present study with the available literature. Given the low incidence of such injuries, multicentric studies are needed to evaluate the inciting circumstances of these injuries.

This study constitutes the first attempt to incorporate GPS and video analysis to evaluate inciting circumstances using a standardised classification system developed by Aiello et al.[10] This method is time efficient and provides detailed information on the injury inciting circumstances. One of the aims of this study was to obtain a more complete understanding of the activities performed by players at the time of injury to provide guidance for practitioners with injury reduction interventions. Using a standard classification system for inciting circumstances and using objective equipment to evaluate players' speed helped to standardise the analysis, although some limitations remain. The reliability of the classification system used in this study has not been evaluated therefore data should be considered carefully, even though two authors analysed the video simultaneously and no disagreement arose. Furthermore, since the study was retrospective it was not possible to systematically interview players, which made it necessary to assume the injuries had occurred at peak speed but this may not always be true. Another limitation of this study is that it was not possible to obtain acceleration data for short periods from the software, as a consequence the average acceleration was obtained by calculating the speed difference between the start and end of the acceleration which were identified by visual inspection. It is unclear whether average acceleration data may be accurate for this type of analysis, but they still provide a good approximation of acceleration intensity. The number of missing data constitutes another limitation of this study. When injuries were not clearly identifiable on video, they were identified asking staff members and/or players. This allowed the analysis of all injuries but one which was not clearly identifiable. Video (6), GPS (21) or both (3) were not available for 37 % (30/80) of cases originally reported as non-contact injuries. Considering the number of missing data and that only one team was involved, the injury circumstance results need to be interpreted carefully, but this study does provide a useful starting point for a more detailed analysis of injury inciting circumstances which can be evolved over time.

5. Conclusion

This study tested a novel approach to obtaining more detailed information of inciting circumstances of elite football player's injuries. The majority of hamstring injuries analysed occurred when players were running over 25 $km \cdot h^{-1}$ and above 80 % of their maximal running speed whilst quadriceps injuries seem to occur whilst players kick the ball. Multiple inciting circumstances were observed for calf (running, jumping) and adductor injuries (kicking, decelerating, receiving the ball). These data are preliminary, therefore further studies are needed. For future studies, involving players in the review of the injury alongside video and GPS/video data may help identify the exact time of injury which could allow more precise analysis.

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Confirmation of ethical compliance

This research has been conducted according to the Declaration of Helsinki. Ethical approval was granted from Edinburgh Napier University Research Integrity Committee (SAS/2786536).

CRediT authorship contribution statement

Francesco Aiello: Conceptualization, Methodology, Formal analysis, Data curation, Visualization, Writing – original draft. **Christian Di Claudio:** Formal analysis, Investigation, Resources, Methodology, Writing – review & editing. **Maurizio Fanchini:** Investigation, Resources, Methodology, Writing – review & editing. **Franco M. Impellizzeri:** Conceptualization, Methodology, Writing – review & editing. **Alan McCall:** Conceptualization, Methodology, Writing – review & editing. **Carwyn Sharp:** Investigation, Resources, Writing – review & editing. **Susan J. Brown:** Conceptualization, Methodology, Writing – review & editing.

Declaration of interest statement

The authors declare that they have no financial or other interests in the products or distribution of the products included in this study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2023.07.007.

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