

Characterising body postures by injury scenarios: a video review analysis of hamstring strain injuries in the National Football League

Tom Myslinski Jr ¹, Naoaki Ito ², Gwansik Park,¹ Leigh Weiss,³ Bryan Heiderscheit,² Eric Sugarman,⁴ John Mellody,⁴ Joe Cormier,¹ Tyler Williams,⁵ Roland Ramirez,⁶ Sam Ramsden,⁷ Kristy B Arbogast,⁸ Jeff R Crandall¹

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For numbered affiliations see end of article.

Correspondence to

Dr Naoaki Ito;
ito@ortho.wisc.edu

ABSTRACT

Objectives The purpose of this study was to (1) establish the agreement of multiple expert reviewers' identification of hamstring strain injury (HSI) scenarios and related body postures among National Football League (NFL) players and (2) determine the prevalence of each HSI scenario and associated body posture in the NFL between 2018 and 2022.

Methods Videos from 305 HSIs in the NFL were reviewed in a blinded fashion by two expert reviewers, who classified the injuries into seven predefined injury scenarios developed by a separate committee of experts. Lower extremity body postures were also identified. Cohen's Kappa coefficients were calculated to determine inter-rater agreement and used to select the subset of injuries to be described via injury scenario and body posture with the intent of minimising bias or ambiguity in reporting.

Results 137/305 (45%) injury videos met the criteria for inclusion in the final dataset based on assessment of classification agreement. Agreement in injury scenario and body posture ranged from poor to moderate. Sprinting injuries were the most common scenario (59/137, 43%). Unique scenarios specific to American football demonstrated the importance of excessive trunk flexion during contact, or during acceleration and change of direction (54/137, 39%).

Conclusions Using a systematic approach involving multiple expert reviewers, sprint-related injury scenarios were highlighted as the most common injury scenario for HSIs. Specific to American football; however, excessive trunk flexion during contact plays or during acceleration and change of direction may be important to consider for injury prevention or rehabilitation from HSIs.

INTRODUCTION

In the National Football League (NFL), lower extremity muscle strains significantly limit athlete participation in practice and games. During the 2015–2019 NFL seasons, 5780 lower extremity muscle strains were reported and 16748 total days were missed.¹ Notably, hamstring strain injuries (HSIs) accounted

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Hamstring strain injuries (HSIs) are the most common lower extremity injuries in the National Football League.
- ⇒ HSI scenarios are commonly classified into sprint, stretch and mixed-type injuries in various sports with high risk of HSI; however, less is known about the injury scenario in American football.
- ⇒ Video review of HSIs may aid in further classifying the scenarios and body postures related to HSIs.

WHAT THIS STUDY ADDS

- ⇒ Sprinting continues to be the most common injury scenario in professional American Football.
- ⇒ Excessive trunk flexion, most seen with contact injury scenarios unique to American football, was another commonly observed body posture.
- ⇒ Current video-based classifications by expert raters have poor agreement, suggesting the need for more systematic and quantitative approaches to video-analysis research.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ Coaches, clinicians and researchers should prioritise the development and implementation of strategies to prevent sprint-related hamstring injuries, which remain the most common mechanism in American football.
- ⇒ Additional research and training that considers trunk flexion during contact scenarios unique to American football may also need to be studied.
- ⇒ Future video-based injury analysis should adopt more rigorous, validated and statistically grounded methodologies to enhance agreement and accuracy in identifying injury mechanisms.

for 55% of all lower extremity muscle strains and were responsible for approximately 9700 player-days missed annually.¹

Research has traditionally classified HSIs into two primary mechanisms, sprint and stretch types.^{2–4} The sprint-type hamstring injury occurs while running at maximum or

near-maximum speeds,^{4–6} while stretch type arises during movements that result in rapid hamstring lengthening, such as during kicking or reaching into wide-split stance positions.^{2–4} Mixed-type mechanisms that combine attributes from the two traditional categories have also been suggested^{4 7 8} due to the dynamic nature inherent in many sports. For example, American football involves reactive movements and combative interactions, which make it more difficult to simply classify injuries as ‘sprint’ or ‘stretch’. There is currently no consensus, however, on further classifying HSI scenarios that apply specifically to American football athletes.

Video review of sports injuries has been used to gain insights into the movements and mechanisms surrounding on-field injury.^{8–12} Video reviews of injuries in the NFL have primarily focused on anterior cruciate ligament injuries,^{13–15} concussions^{16 17} and ankle injuries.^{18–20} HSIs in the NFL, however, have not been investigated in depth. Further classification of the injury scenario and body posture at the time of HSIs has been studied in other sports such as soccer and rugby,^{7–12} but not in American football. Classifying the injury scenarios and body postures of American football athletes at the time of injury may be an important step in advancing the prevention and rehabilitation of HSIs.^{8 21}

A key concern in previous studies on injury scenario classification and determining body posture at the time of injury is the methodological heterogeneity and the lack of established agreement in the approach. While many studies report interpretations of video analyses,^{9 10 12 22} it remains uncertain if other experts in the field would arrive at similar conclusions when reviewing the same injury videos. This uncertainty is compounded by the fact that most studies do not report the repeatability in their injury classification systems and rely on various expert opinions over quantitative methods, which may bias interpretations. Recent work has called for consensus on the best, reliable approach for video analysis²³ to effectively interpret and apply findings from video-based injury scenario reviews. Through this study, we aim to establish and advance current methodology in video review analyses in sports medicine by integrating assessments by multiple expert reviewers and implementing agreement statistics.

The purpose of this study was to (1) establish the reproducibility of the identification of HSI scenarios and related body postures from multiple expert reviewers and (2) determine the prevalence of each HSI scenario and associated body postures in the NFL between 2018 and 2022.

METHODS

Study design and participants

This retrospective cohort study included all NFL players who sustained an HSI during games throughout the 2018–2022 seasons. Injury data for all NFL players are collected by club medical staff through a mandated process outlined by the NFL’s Collective Bargaining Agreement

with the NFL Players Association (NFLPA) and are collectively maintained within the NFL’s electronic medical record system (EMR). Each medical record contains information regarding the player’s activity, position and quarter in which the injury was thought to have occurred. Approvals were obtained through the NFL–NFLPA Player Scientific and Medical Research Protocol²⁴ required by the Collective Bargaining Agreement and by the Advarra Institutional Review Board (Pro00074031).

Data acquisition

The NFL EMR was queried for HSIs sustained during a game within the 2018–2022 seasons. The primary hamstring muscle involved (biceps femoris, semimembranosus, semitendinosus and unspecified muscle) was also extracted to categorise prevalence by muscle. The primary muscle involved was determined by club medical staff based on a combination of clinical examination and imaging findings when available. Only HSIs resulting in a player missing all or a portion of a practice or game were included. Injuries were then linked to the Game Statistics and Information System, which was used for identification and analysis of each injury.

Injury scenario and time of injury identification

Videos were imported to a custom video review application including three or four standardised perspectives: (1) Sideline—an elevated view from the sideline of the field, capturing all players on the field; (2) Endzone—one or both views from the endzone area, focusing on the middle of the field and (3) Television—comprehensive network broadcast footage. All videos were recorded at 60 Hz (figure 1).

HSIs reviewed in the current study were restricted to those that were acute onset,²⁵ defined as injuries where athletes demonstrated clear visible signs of an HSI, followed by removal from the game. Signs of HSIs included players grabbing their posterior thigh, a visible limp or hopping on the uninvolved leg (ie, avoiding weight bearing). Only in-game footage was used for standardisation of videos and for completeness of data, as not all practice injuries can be captured on video. To provide reviewers with the best context of the injury, only injuries where two or more clear, unobstructed views of the injury were available were included in this study (figure 2).

The initial step to develop injury scenarios was performed by a committee of five experts (LW, BH, TW, RR and SR). Video editing software (Blender 3.5, Blender Foundation, Amsterdam) was used to review footage. Each committee member reviewed a subset of the injury videos (n=43) and through discussions, came to a consensus on seven injury scenarios and detailed descriptions (table 1) for the most common injury scenarios specific to American football. The body posture classifications (table 2) were created by the expert committee with the intent of simplifying the classification by limiting options to less than three categories and selecting joint angles with a minimum of 15° intervals. Reviewers were intentionally



Figure 1 Example of still frame from custom video review application for body posture review: The upper image shows a zoomed-in view of the players from the endzone perspective, while the lower image displays a zoomed-in view of the players from the sideline perspective. Used with permission from the NFL. NFL, National Football League.

not asked to provide an exact joint angle. This approach was taken since agreement for more detailed classifications based on expert interpretation of video analysis alone is unknown and expected to demonstrate worse agreement. We aimed to study and report on a simple body posture classification that may be reproduced by various expert reviewers.

For each injury in the final dataset ($n=137$), two reviewers (TMJ and GP) independently identified the single frame associated with the time of injury. Any discrepancies identified in the frame at the time of injury were openly discussed by the review committee. If consensus was not met, the injury was excluded from further analysis.

Video review

Two additional blinded expert reviewers (JM and ES) with 20 and 25 years of experience as athletic trainers working with American football, who were not a part of the original expert panel and blinded to each other's selections, then re-evaluated each video included in analysis.

The two reviewers also went through a 1-hour training session where the original panel members discussed the definitions outlined in [table 1](#), explained the evaluation platform and answered any clarifying questions. They identified the body posture ([table 2](#)) at the time of injury and the injury scenario ([table 1](#)). Both reviewers were given the option to select 'unable to assess' for every classification.

For each injury, the reviewers were initially only presented with a still frame of at least two camera views at the predetermined time of injury. In this frame, reviewers only determined the body posture (and not the injury scenario) to limit biasing their interpretation of body posture from the remainder of the injury video.

Once body posture categorisations for a certain injury video were identified, they were finalised, and no further modifications could be made. The process then moved to the next stage, where the video showing the injury from 2s prior to the moment of injury was presented. The reviewers then selected the injury scenario ([table 1](#)).

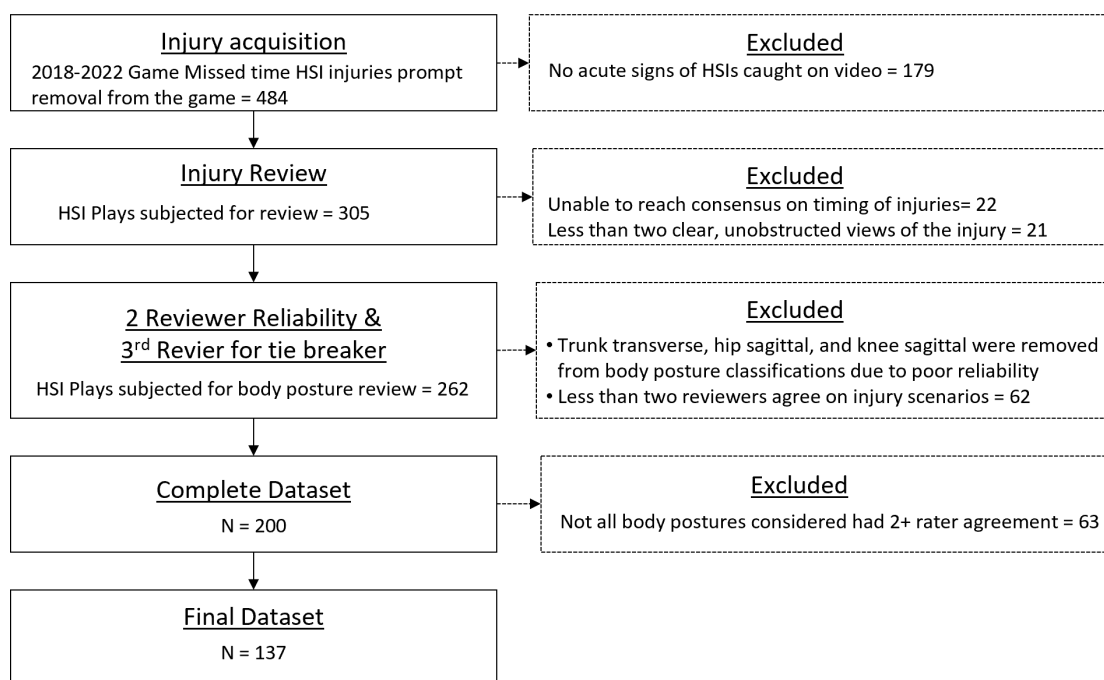


Figure 2 Flowchart for selecting videos for review and analysis. HSI, hamstring strain injury.

Given the variability in obstruction to the athlete or camera angle depending on the location of injury relative to the field, reviewers were encouraged to choose the option of ‘unable to assess’ for both the selection of body postures and injury scenarios if they had less than optimal confidence in their interpretation.

Agreement statistics

Cohen’s kappa²⁶ was used to calculate agreement between the two reviewers for the injury scenarios and each body posture. Given the possibility of skewed distribution in the classification of data given prior knowledge (ie, HSIs are known to be most common in positions of knee extension and hip flexion), Gwet’s agreement coefficient (AC1), which accounts for skewed data, was also reported.²⁷ If either or both reviewers deemed the

classification ‘unable to assess’, that instance was removed from calculating the statistics.

Categorisation of body posture and injury demographics by injury scenarios

For reporting of body postures, we included classifications where the agreement was moderate or better (kappa >0.41) or had higher than 75% agreement between the reviewers to avoid reporting on body posture categorisations that are not reproducible with confidence. Injury scenarios were reported regardless of the agreement observed, as this classification serves as the anchor to classify the body postures further. To maximise the sample size, a third expert reviewer from the original committee conducted the video analysis. Only injuries where two or more reviewers agreed on

Table 1 Injury scenario classifications and definitions presented to the reviewers

Injury scenario	Definition
Sprinting	The player was running at high speed with no sudden change in direction or speed
Deceleration	The player reduced movement speed; direction of motion generally remained the same; may come to a complete stop but not necessary
Acceleration	The player increased movement speed; direction of motion generally remained the same
Change of direction	The player had an abrupt change in direction of motion but did not come to a complete stop
Balance control	The player reached out with their leg in an attempt to maintain or regain control of their centre of mass. Examples include, but are not limited to, falling or landing from a jump
Forward trunk pitch	The player rapidly flexed their trunk towards their thigh, and/or their knee was rapidly hyperextended with the flexed trunk. Can occur either actively or passively from contact. Examples include reaching out to catch a ball, reaching down to pick up a ball, avoiding another player, and contact with another player.
Kicking	The player was actively kicking or punting the football

Table 2 Definition of body postures presented to the reviewers

Variable	Classifications	Descriptions
Player contact status	► Contact ► Non-contact ► Unable to assess	Defined as contact/non-contact based on the single frame at the time of injury. Any type of contact from any other player in the single frame, including from tackling, pushing, grabbing of jersey or protective gear, etc., was considered contact.
Injured/non-injured limb ground contact	► Yes ► No ► Unable to assess	Classification was based on a comprehensive assessment of all video views and defined as yes/no based on whether the foot had any contact with the ground in the frame. For example, heel off the ground but toes on the ground counted as ground contact.
Trunk sagittal	► Less than 30° flexion ► Between 30 and 60° flexion ► More than 60° flexion ► Unable to assess	Classified into three categories based on the best sagittal video view. The trunk flexion angle was defined from vertical (0°) to the ground and not relative to the pelvis.
Trunk frontal	► More than 15° lateral flexion towards injured leg ► Less than 15° lateral flexion to either direction ► More than 15° lateral flexion towards non-injured leg ► Unable to assess	Classified into three categories based on the best frontal video view. Trunk lateral flexion was defined from the vertical (0°) to the ground not relative to the pelvis.
Trunk transverse	► Towards the injured leg ► Away from the injured leg ► Unable to assess	Classified into two categories based on the best available views. Trunk rotation was defined as relative to alignment when the shoulders and pelvis are vertically aligned. Eg, For a left HSI, if the left shoulder is behind the left pelvis and/or the right shoulder is in front of the right pelvis, then the classification is 'towards the injured leg'.
Hip sagittal	► Less than 45° flexion ► Between 40 and 90° flexion ► More than 90° flexion ► Unable to assess	Classified into three categories based on the best sagittal video view. The hip flexion angle was defined from the trunk to the thigh. Standing vertically was defined as 0°
Hip frontal	► More than 15° abduction (away from midline) ► Less than 15° ab/adduction ► More than 15° adduction (across midline) ► Unable to assess	Classified into three categories based on the best frontal video view. Hip ab/adduction angles were defined from the trunk to the thigh. Standing vertically was defined as 0°, and across the midline of the body was adduction, and away was abduction.
Knee sagittal	► More than 45° flexion ► Between 15 and 45° flexion ► Less than 15° flexion (includes hyperflexion) ► Unable to assess	Classified into three categories based on the best sagittal video view. The knee flexion angle was defined from the thigh relative to the lower leg. Full knee extension was 0° flexion.

the injury scenario were included. We then reduced the sample to injuries where all selected body posture categories for a given injury were successfully classified (ie, at least two of the three reviewers agreed), again to avoid selective or biased reporting of the distribution in body postures. The overall intent of this approach was to eliminate any ambiguity in classification and to only report on injuries where a clear view with the best available agreement on body posture by expert raters was obtained. To ensure that there was no bias between the videos removed versus those that were kept in analysis, we compared the scenario distribution in the final included cases to all reviewable cases. We then further reported on the injury scenarios by position group ([table 3](#), position

groups defined in online supplemental table A1) and the primary hamstring muscle involved for additional clinical context ([table 4](#)).

RESULTS

Agreement statistics

[Table 5](#) presents the agreement statistics for all variables, with the corresponding contingency tables (online supplemental table A5 through A14). Injury scenarios had fair agreement (Cohen's Kappa (95% CI) 0.385 (0.316 to 0.454)) between two expert reviewers, with 53% overall agreement among the seven injury scenarios. Reviewer 1 identified 11 injuries, and reviewer 2 identified 12 injuries as 'unable to assess', of which both reviewers

Table 3 Injury scenarios by position group

Position group	Injury scenarios (n=137)						
	Sprinting (n=59)	Deceleration (n=12)	Acceleration (n=12)	Change of direction (n=17)	Balance control (n=15)	Forward trunk pitch (n=20)	Kicking (n=2)
Skill	66%	67%	75%	65%	60%	40%	0%
Hybrid	25%	17%	17%	24%	13%	20%	0%
Power	8%	17%	8%	12%	27%	40%	0%
Special team	0%	0%	0%	0%	0%	0%	100%

agreed the injury was ‘unable to assess’ on just 1 of the 22 injuries (less than 5%). Agreement statistics in body postures varied from no agreement to substantial agreement (Kappa=0.065–0.760). Player contact and limb ground contact variables had the best percent agreement (agreement=90% and 82%–93%, respectively), followed by trunk sagittal (75%) and hip frontal plane angles (75%). Trunk frontal plane had 76% agreement, but only poor agreement based on Cohen’s Kappa (0.290). This discrepancy, however, was likely due to the skewed distribution of classifications favouring the neutral position, and Gwet’s AC1 value of 0.719 reflects this finding. Knee and hip sagittal plane and trunk transverse plane angles demonstrated fair or no agreement and hence were removed from subsequent analysis.

Categorisation of body posture and injury demographics by injury scenarios

Based on agreement statistics, six variables (player contact status, injured and non-injured limb ground contact, trunk sagittal and frontal plane angle and hip frontal plane angle) were included for the final categorisation of body posture by injury scenario. Out of 305 HSI videos identified, 21 (7%) were excluded for poor video quality and 22 (7%) were labelled ‘unable to assess’ by at least one reviewer. After obtaining a third-reviewer opinion on disagreements, 200 injuries (76% of 262 assessable cases) achieved a consensus on the scenario. Finally, 137 injuries (45% of the original 305) had complete agreement on all retained body posture variables and were included in the detailed analysis. Table 6 summarises body posture characteristics across various injury scenarios identified in the final included injuries. We also found that the

distribution of injury scenarios in the reduced sample, including only those with complete body posture agreement, was similar to that prior to removal of those without complete body posture agreement (online supplemental table A2).

DISCUSSION

This study is the first of its kind to evaluate HSI injury scenarios and associated body postures in the NFL. To our knowledge, this is the lone injury video analysis study that determined categories to include in analysis by using robust methodology incorporating agreement statistics. Even with expert reviewers and a simple classification system, agreements in injury scenarios and body postures at the joint level are moderate at best. Better agreement was seen for the simpler, player and ground contact variables where outcomes were binary (ie, yes or no). Even with the removal of joint posture categories with fair to no agreement and a tie-breaker style evaluation by a third expert reviewer, our approach only retained 45% (137/305) of all injury videos included in the analysis. Poor video quality accounted for 7% (21/305) of removal from analysis, and expert reviewers were unable to come to a consensus on the remaining 48% (147/305) of the injuries. In return, in the final dataset, we have the greatest confidence that our reported data have minimal bias or ambiguity and a high reproducibility in the classifications reported.

Our final body posture classifications by injury scenario confirmed prior results known in the HSI mechanism literature^{7–10 12 22 25} and also revealed several characteristics of HSIs that may be unique to American football.

Table 4 Injury scenarios by primary hamstring muscle involved

Muscle	Injury scenarios (n=137)						
	Sprinting (n=59)	Deceleration (n=12)	Acceleration (n=12)	Change of direction (n=17)	Balance control (n=15)	Forward trunk pitch (n=20)	Kicking (n=2)
Biceps femoris	69%	50%	75%	65%	40%	40%	50%
Semimembranosus	7%	0%	8%	0%	7%	15%	0%
Semitendinosus	10%	17%	0%	0%	7%	5%	0%
Muscle unknown	14%	33%	17%	35%	47%	40%	50%

Table 5 Agreement statistics for injury scenarios and body postures

	Agreement	Cohen's Kappa (95% CI)		AC1 (95% CI)	
Player contact status	90%	0.760	(0.677 to 0.848)	0.822	(0.754 to 0.890)
Injured limb ground contact	93%	0.285	(0.042 to 0.529)	0.924	(0.886 to 0.961)
Non-injured limb ground contact	82%	0.560	(0.462 to 0.676)	0.687	(0.596 to 0.778)
Trunk sagittal	75%	0.583	(0.495 to 0.670)	0.647	(0.569 to 0.725)
Trunk frontal	76%	0.290	(0.158 to 0.423)	0.719	(0.647 to 0.792)
Trunk transverse	54%	0.065	(−0.119 to 0.250)	0.079	(−0.110 to 0.268)
Hip sagittal	67%	0.263	(0.148 to 0.378)	0.576	(0.494 to 0.658)
Hip frontal	75%	0.515	(0.410 to 0.620)	0.669	(0.588 to 0.749)
Knee sagittal	58%	0.253	(0.163 to 0.343)	0.425	(0.336 to 0.514)
Injury scenario	53%	0.385	(0.316 to 0.454)	0.426	(0.336 to 0.514)

AC1, Gwet's agreement coefficient.

Table 6 Body posture by injury scenarios from the final included injury videos

	Injury scenarios (n=137)						
	Sprinting	Deceleration	Acceleration	Change of direction	Balance control	Forward trunk pitch	Kicking
	(n=59)	(n=12)	(n=12)	(n=17)	(n=15)	(n=20)	(n=2)
Player contact status							
Contact	14%	17%	25%	18%	60%	75%	0%
Non-contact	86%	83%	75%	82%	40%	25%	100%
Injured limb ground contact							
Yes	98%	100%	100%	100%	100%	100%	0%
No	2%	0%	0%	0%	0%	0%	100%
Non-injured limb ground contact							
Yes	7%	17%	25%	29%	13%	65%	100%
No	93%	83%	75%	71%	87%	35%	0%
Trunk sagittal							
Flexion<30°	90%	92%	33%	29%	27%	20%	100%
30°≤flexion<60°	8%	8%	58%	71%	33%	25%	0%
60°≤flexion	2%	0%	8%	0%	40%	55%	0%
Trunk frontal							
Lateral flexion<15° (either direction)	97%	100%	92%	76%	60%	50%	50%
15°≤lateral flexion (towards injured leg)	2%	0%	8%	18%	20%	45%	50%
15°≤lateral flexion (towards non-injured leg)	2%	0%	0%	6%	20%	5%	0%
Hip frontal							
15°≤abduction	2%	33%	33%	47%	27%	60%	0%
Ab/adduction<15°	93%	58%	58%	24%	73%	35%	50%
15°≤adduction	5%	8%	8%	29%	0%	5%	50%

'Sprinting' and 'Deceleration' injury scenarios demonstrated nearly identical distribution of body postures consistent with what has traditionally been called sprint-type injuries. Positions with greater running-related responsibilities, such as skill and hybrid athletes, were most likely to sustain these types of injuries. These were commonly non-contact injuries sustained with an upright trunk with minimal mediolateral lean while the injured limb is in contact with the ground. 'Deceleration' injuries had slightly higher proportion of the hip frontal plane deviating from neutral. This may be attributed to the nature of when athletes decelerate and are more often moving in a non-linear manner compared with when they sprint. 'Acceleration' injuries, another linear sprint-related injury scenario, more often occurred with the trunk further into flexion compared with 'Sprinting' or 'Deceleration' injuries. The hamstrings are thought to be most susceptible to injury when sprinting above 80% of maximum speeds.^{5 6} Despite slower speeds during acceleration, athletes may still be at high risk of sustaining an HSI due to the trunk being in further flexion and elongating the hamstrings. The 'Change of Direction' injury scenario is another example that likely occurred at less than 80% sprint speeds and was paired with greater trunk flexion angles. These injuries were also commonly associated with greater hip frontal plane deviation from neutral compared with 'Deceleration' or 'Acceleration' injuries. The trend we observed in hip frontal plane position, however, was less clear, and its relevance to HSIs is difficult to derive with the current data. Overall, the running-related injury scenarios reflected the known high prevalence and commonly reported body postures associated with HSIs, emphasising the importance of hamstring loading protocols and progressive exposures to sprinting to minimise risks of HSIs. Trunk flexion angles, however, may be of additional interest to consider in relation to running and HSI risks, particularly in the context of submaximal speed running scenarios such as accelerating or changing direction during American football or other sports that involve similar manoeuvres.

The 'Balance Control' and 'Forward Trunk Pitch' injury scenarios were less common (26% of injuries) but demonstrated body postures that may be unique to the combative nature of American football. These two injury scenarios were exclusively sustained with the injured limb in contact with the ground and trunk in a large amount of flexion, with the majority being classified as contact injuries. The 'Forward Trunk Pitch' scenario was also the most common injury scenario with both limbs in contact with the ground. Unlike the running-related injuries discussed above, these injury scenarios were likely not sustained due to excessive hamstring forces from running, but rather from rapid elongation of the hamstrings from sudden, excessive trunk flexion. These types of injuries were also more common in hybrid and power positions, where a greater amount of player contact is expected. While a portion of these injuries were non-contact in nature, most had some level of player contact, potentially

making the prevention of these types of injuries much more difficult in a sport such as American football that involves complex movements. There may, however, be value in further investigating strategies, such as trunk strengthening exercises, to prevent the excessive trunk flexion commonly associated with these types of injuries.

Findings from this study emphasise the importance of statistics-driven evaluation of methods when performing injury video analyses. Future studies can expect to lose a large proportion (over half in this study) of the injuries analysed due to limitations in agreement. This may particularly be the case if more specific categorisations (eg, joint angles by 5° increments) compared with our approach are used. The expected loss of data, however, will be driven based on the quality of videos collected and the target agreement percentage defined for analysis. Readers must also acknowledge that this data loss is not necessarily a weakness of the approach, but rather a strength that allows for improving confidence in the data. We believe our approach outlines a template for a more robust and systematic alternative to what has traditionally been done in the field. With advancements in player tracking, including next-generation statistics in the NFL for tracking player location and speed during games, or motion capture technology,^{28–32} video review of injuries may become an obsolete methodological approach in the future. Validation between video analysis and newer methods may also be an important interim step that may be necessary for the translation of findings. Until then, having a large sample size and using a systematic approach that involves multiple expert reviewer consensus, along with understanding the limitations of the classifications applied, it is imperative to confidently report video analysis results that are applicable and clinically meaningful to the broader community.

There are some limitations to acknowledge in this manuscript. Our video inclusion criteria of player visibility and quality, and our footage limited to in-game time loss injuries, may have disproportionately eliminated certain types of injury scenarios. For example, scenarios where there is higher player density in view, more contact, and player obstruction of videos may make it much more difficult to categorise. In this cohort, however, there was minimal difference in injury scenario distributions before and after removal of the cases without complete agreement for all body postures. There is further work needed to improve video analysis approaches, so all types of injuries and plays can be reported without potentially under-representing specific injury scenarios due to methodological limitations. Additionally, our body posture analysis is based on the assumed time of HSI. This is particularly difficult to objectively quantify during fast movements, and our interpretation of body posture is limited to the single frame on which our expert panel agreed. Given the retrospective nature of the study, there is no conclusive evidence to support that addressing or avoiding the body postures commonly associated with HSIs will necessarily translate to injury reduction. The

findings from this study, however, can provide future longitudinal or intervention-based studies with some insight into potential factors to address.

CONCLUSION

This study demonstrated common body postures and injury scenarios associated with the highly prevalent HSIs in the NFL. As with other sports, HSIs were most frequently sustained during sprinting. Our study additionally identified unique injury scenarios and body postures that may be specific to American football or other sports that involve similar manoeuvres, such as excessive trunk flexion during acceleration or change in direction, and particularly during player contact situations. These scenarios and body postures may be of particular interest to consider in the injury prevention and rehabilitation from HSIs for American football athletes. The methodological findings highlighting the poor agreement in many of the injury scenarios and body posture classifications underscore the importance of systematic, statistical-driven video analysis and the need for continued improvements in this approach. Advances in technology, however, may help address current limitations, offering potential for more accurate and complete injury analysis in the future.

Author affiliations

¹Biomechanics Consulting & Research LLC, Charlottesville, Virginia, USA

²Department of Orthopedics and Rehabilitation, University of Wisconsin-Madison, Madison, Wisconsin, USA

³New York Football Giants, East Rutherford, New Jersey, USA

⁴National Football League, New York, New York, USA

⁵Minnesota Vikings Football LLC, Eden Prairie, Minnesota, USA

⁶Houston Texans, Houston, Texas, USA

⁷Seattle Seahawks, Seattle, Washington, USA

⁸Center for Injury Research and Prevention, The Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, USA

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for the data provided to this system to be used in furtherance of certain research approved by the NFL and the NFLPA. Approval for this study was obtained through the NFL-NFLPA Collective Bargaining Agreement and the NFL Player Scientific and Medical Research Protocol. Participants gave informed consent to participate in the study before taking part.

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ORCID iDs

Tom Myslinski Jr <http://orcid.org/0009-0006-1713-121X>

Naoaki Ito <http://orcid.org/0000-0003-4166-5319>

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