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Combining Data From Injury Surveillance and Video Analysis Studies: An Evaluation of Three FIFA World Cups™

By Jaakko Ryynänen, Louis Leventer, Lars Peterson, Hannu Kautiainen, Jón Karlsson, Mats Börjesson & Colin W Fuller
Sahlgrenska University, Sweden

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Jaakko Ryynänen [α], Louis Leventer [σ], Lars Peterson [ρ], Hannu Kautiainen [ω], Jón Karlsson [¥], Mats Börjesson [§] & Colin W Fuller [χ]

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Conclusions: The limitations of combining injury report data with data obtained through video analysis make the results of the present study difficult to interpret. There is limited evidence that the current definition of an injury risk incident, as defined in the FIA methodology, is adequate for linking match events with injuries. Future studies are needed that provide more reliable methods for identifying injuries using video recordings.

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Author α: Department of Orthopaedics, Sahlgrenska University Hospital, Gothenburg University, Gothenburg, Sweden, University of Helsinki, Faculty of Medicine, Helsinki, Finland.
e-mail: Jaakko.ryynanen@helsinki.fi
Author σ: Faculty of Sport and Health Science, Technische Universität München, Munich, Germany.
Author ρ: Department of Orthopaedics, Sahlgrenska University Hospital, Gothenburg University, Gothenburg, Sweden, FédérationInternationale de Football Association (FIFA), Zurich, Switzerland.
Author ω: Helsinki University Central Hospital, Unit of Primary Health Care, Helsinki, Finland, University of Helsinki, Department of General Practice, Helsinki, Finland.
Author ¥: Department of Orthopaedics, Sahlgrenska University Hospital, Gothenburg University, Gothenburg, Sweden.
Author §: Swedish School of Sport and Health Sciences, Stockholm, Sweden,Department of Cardiology, Karolinska University Hospital, Stockholm, Sweden.
Author χ: FédérationInternationale de Football Association (FIFA), Zurich, Switzerland.

I. Introduction

Football is one of the most popular sports in the world, but it also carries a significant risk of injuries.[1-6, 7, 8] Therefore research on the epidemiology and prevention of football injuries is of major importance. In a four-step model for injury prevention in sports, van Mechelen, suggested that preventive measures should be based on knowledge of the etiology and the mechanisms of injuries.[9]

Video analysis of injuries in football has been increasingly used for describing injury circumstances or playing actions leading to injury.[10, 11, 14-18, 24, 25] investigating the mechanisms of injuries,[12, 13, 27] and for studying tackles.[15, 26] In addition, video analysis has been used for assessing the accuracy of referees' decisions and assessing whether the laws of the game should be modified in order to prevent injuries.[22, 23] The methods have, so far, been more useful for describing playing situations and athlete/opponent movements than evaluating joint biomechanics.[28]

Andersen et al. described a video-based method, FIA (Football Incident Analysis), for analysing what were referred to as "injury risk incidents" using football-specific variables.[16] According to the FIA methodology, an injury risk incident referred to any situation in which the match was interrupted by the referee, a player was on the ground for more than 15 seconds, or a player appeared to be in pain or received on-pitch medical treatment.[14, 16,18, 23, 29] Previous studies combining injury data, based on reports from the medical teams, and injury risk incident data, obtained by FIA, have shown that linking non-contact injuries with injury risk incidents is more difficult than linking contact injuries with injury risk incidents.[14, 18] FIA, which was developed as a descriptive tool for analysing playing actions leading to injury risk incidents, has since been applied in several studies.[14, 18, 23, 29] When using FIA, injury risk incidents are defined according to 19 variables, each with two or more categories related to playing actions preceding the incident.[16] To date, no clear patterns for the playing situations leading to injuries have been identified that link FIA incidents with resultant injuries; however, the

injury risk associated with individual variables has not previously been studied.

Fuller et al.[15] performed video analysis of all tackles in three FIFA tournaments. They were able to identify certain tackle parameters that were associated with a higher risk of injury than others.[15] Their methods did not, however, take into account match events or the circumstances leading up to the tackles. Tscholl et al.[26] combined the FIA and the tackle analysis video methods and found that certain tackles were more frequently sanctioned by the referee than others.[26] However, they found that the factors leading to injury risk incidents (as defined in the FIA methodology) and the factors leading to injuries to be different, and thus, questioned whether equating injury risk incidents with the risk of injury was valid.[26]

The playing actions leading to injury risk incidents, as defined in the FIA methodology, have not yet been analysed using video recordings in top-level international male football. As the injuries sustained during the three most recent men's FIFA World Cups, and the match circumstances in which these injuries occurred, have been extensively studied based on injury report data and match statistics,[1, 4, 7, 30, 32, 39] performing an additional video analysis of the circumstances leading to these injuries might add to the understanding of the circumstances and playing actions leading to football injuries in top-level football.Such a study would also provide an insight into the benefits and limitations of the current methods of video analysis and enable evaluation of whether current video analysis methodologies complement or conflict with results from injury surveillance studies.

The aims of the present study were to:

1) analyze, using current video analysis methodologies, the playing actions and match circumstances that involve physical contact between players and lead to injury in men's World Cup football and to
2) assess whether the variables used for FIA have independent injury predictive value when compared to data obtained from injury surveillance studies.

II. Material and Methods

The study cohort consisted of complete video recordings of all 192 matches played during the 2002, 2006 and 2010 men's FIFA World Cups™, 441 injury reports of the match play injuries sustained during these three tournaments, as well as match statistics for all the matches provided by FIFA's official website.[36]

a) Definitions of injury and injury risk incident

An (FIFA) injury was defined as any physical complaint incurred during a match that received medical attention from the team physician regardless of the consequences with respect to absence from match play or training.[1-4, 7]An (FIA) injury risk incident was defined as any situation in which the match was interrupted by the referee, or a player was on the ground for more than 15 seconds, or the player appeared to be in pain or received medical treatment (as defined in the FIA methodology).[14, 16,18, 23, 29]A contact injury was defined as any injury resulting from physical contact between players, and a contact injury risk incident, was defined as an injury risk incident that resulted from physical contact between players.

b) Injury surveillance reporting

The post-match injury report forms, completed by team physicians, have been presented in previous studies of FIFA tournaments.[1-4, 7]Only contact injuries were included in the present study, as non-contact injuries have previously been shown to be difficult to link with FIA injury risk incidents,[14, 18] and as most injuries in men's World Cup football result from contact between players.[1-4, 7] The injury surveillance reporting followed the consensus statement for injury definitions and data collection procedures for epidemiological studies on football injuries.[20] Ethics approval for the injury surveillance study was obtained.

c) Video analysis and linking injuries with injury risk incidents

All contact injury risk incidents were reviewed, using FIFA video recordings of all matches by one author (LL), who was experienced in video analysis. In order to identify the contact injury risk incidents associated with post-match injury reports, the details of each contact injury risk incidentwere compared to the FIFA injury surveillance reporting data in terms of the time of incident, the player's shirt number, and the injury type and location. The following eight established FIA variables (categories), [16] with some minor modifications, were used in the analysis:

- Ball possession (defence or attack).
- Attack type (set play, breakdown attack, long attack including long pass, long (organized) attack).
- Degree of balance in opponents' defence (good, average, poor)
- Player's position (defender, midfielder, forward, goalkeeper)*
- Player's action with the ball (dribbling, heading, deflecting the ball, kicking the ball, goalkeeper action, no action with the ball)**
- Player's movement intensity (high intensity, low intensity).
- Player's attention (towards primary duelist, the ball, team mate, other)***
- Referee's decision (foul, non-foul)****

*Modification: The number of playing positions was reduced to the four general categories, in order to allow comparison of the results with those obtained from a previous study of injuries in FIFA World Cup football.[30]

**Modification: Some of the originally proposed 14 categories were combined in order to avoid the previously described problem of having too few cases in some categories.[16]

***Modification: the category "other" was added, as the player's attention was sometimes directed elsewhere (e.g. coach/crowd//the pitch/ goal/ unknown etc.)

****Modification: the category "foul" included the awarding of a yellow or red card, in order to simplify the analysis.

The main reason for combining some categories was to avoid a problem identified in previous studies; namely, too many categories with small number of cases.

The variables "player's action with the ball", "player's movement intensity", "playing position" and the tackle parameters (included in the present study) were considered to fully describe a player's actions, role, and the contact mechanisms in the context of the present study. Therefore, the following original FIA variables,[16] were excluded:

- positioning
- player's role
- duel type
- ball winning situations
- player's movement direction
- tackling type
- type of incident risk action
- degree of individual ball control

Similarly, "ball possession", "attack type" and "degree of balance in the opponent's defence" (included in the present study) were thought to describe the team's actions and situations sufficiently for the context of the present study; thus, the following team-related original FIA variables,[16] were also excluded:

- Team action before injury incident
- Attack effectiveness

Additionally, the variable "localization on the field" [16] was excluded, as the main focus of the present study was on match circumstances, playing actions and tackle parameters, rather than the localization of the incident on the field. The playing actions included in the present study were also not always directly related to a specific location on the field (e.g. "attack type").

d) Added variables

The following variables, previously shown to be associated with injury incidence in the 2002, 2006 and 2010 men's FIFA World Cups were added to the analysis:

- Current score (team in focus of the incident losing, drawing or winning).[30]
- Match period (minutes 0-15, 16-30, 31-45+, 46-60, 61-75, 76-90+ or extra time.[1, 4, 7, 30]

e) Tackle analysis

A tackle was defined as any event that occurred during the normal course of the match and involved physical contact between two or more players while one or more of the players challenged for possession of the ball.[15, 17, 22, 25, 26]The contact injury risk incidents that involved a tackle were also analyzed using the tackle parameters proposed by Fuller et al.,[15] with the addition of one new category within the tackle action parameter (*):

- Tackle direction (front, side or behind)
- Tackle mode (on feet, sliding in, vertical jump)
- Tackle action (one-footed, two-footed, use of arm/hand, upper body contact, clash of heads, combination*)

* The new 'combination' category included tackles involving more than one simultaneous tackle action, as some tackle incidents were found to involve several simultaneous actions that had the potential to cause an injury.

Tackle parameters associated with contact injury risk incidents involving a tackle, that were identified by video analysis and which were also linked to a post-match reported injury, were compared with parameters associated with injury risk incidents involving a tackle, identified by video analysis that could not be linked with a post-match reported injury.

f) Statistical analysis

Ratios of the variable categories associated with contact injury risk incidents that were (a) linked with an injury and (b) not linked with an injury were calculated, in order to assess the injury predictive value of each variable category. Logistic multivariate regression models with robust estimate of variance were used to investigate the variables related to the contact injury risk incidents.Comparisons between groups were made by the chi-square test. The tackle parameters were not analysed in the same multivariate regression model with the other variables, as they formed a separate and predetermined group.[15] As there were only three tackle parameters, a multivariate regression analysis of them was not performed and comparisons between the categories of tackle parameters were made by the chi-square test.The level of significance was set at p-values <0.05. Intra-observer reliability was tested by reviewing and reanalysing 10% of the contact injury risk incidents (randomly chosen from the three tournaments and including a re-analysis of 23 different teams): a minimum of 3 weeks was allowed between the two assessments, in order to reduce potential learning bias. The agreement between the two sets of results was determined by the kappa statistic (κ). The level of agreement was defined as follows, poor:$\kappa=0.20$; fair:$\kappa=0.21$ to 0.40; moderate:$\kappa=0.41$ to 0.60; substantial: $\kappa=0.61$ to 0.80, and very good:$\kappa>0.80$.[34]

The STATA 12.1, StataCorp LP (College Station, TX, USA) statistical package was used for the analyses.

III. Results

The 192 matches resulted in 441 injuries being reported within the FIFA match-day injury surveillance system, of which 304 were contact injuries: in addition, 671 contact injury risk incidents were identified from the video recordings of these matches. One hundred and twenty-eight (42.1%) of the 304 reported contact injuries were linked with a corresponding contact injury risk incident. The intra-rater reliability for the video analysis of contact injury risk incidents was very good (κ=0.88-0.98) for all variables and tackle parameters.

From the FIA video analysis, two variables were identified as independent predictors of injury; attack type ($p<0.01$) and the involvement of foul play ($p<0.05$). Long attacks had the lowest ratio of contact injury risk incidents linked with injuries compared to other contact injury risk incidents. The involvement of foul play in the contact injury risk incidents was associated with a significantly smaller ratio of contact injury risk incidents linkable with injuries/other contact injury risk incidents, compared with the contact injury risk incidents not involving a foul. Table 1 summarizes the study results and the results of the regression analysis.

Table 1. The numbers of both the contact injury risk incidents that were not linkable with an injury and those that were linked with an injury, as well as their relative proportions for all the categories of each variable. Additionally, the results of the multivariate regression analysis, with the relative risk (OR*) for each category, as well as the significance of differences in the relative risks between the categories of each variable.

	Descriptive data		Results of multivariate regression analysis	
Variables and categories	Number of FIA contact injury risk incidents without linkable FIFA injuries (%)	Number of FIA contact injury risk incidents with linkable FIFA injuries (%)	OR* (95%CI)	p-value
All variables	543 (80.9)	128 (19.1)		
Ball possession				0.86
Defense	222 (80.7)	53 (19.3)	1 (Reference)	
Attack	321 (81.1)	75 (18.9)	1.05 (0.64-1.69)	
Attack type				0.01
Set play	69 (75.8)	22 (24.2)	1 (Reference)	
Breakdown attack	132 (76.7)	40 (23.3)	0.99 (0.50-1.94	
Long attacks, including a long pass	83 (72.2)	32 (27.8)	1.17 (0.57-2.40)	
Long attacks	259 (88.4)	34 (11.6)	0.42 (0.22-0.84)	
Current score				0.23
Losing	96 (79.3)	25 (20.7)	1 (Reference)	
Drawing	240 (77.7)	69 (22.3)	0.99 (0.56-1.75)	
Winning	207 (85.9)	34 (14.1)	0.64 (0.33-1.26)	
Degree of balance in opponents' defense				0.22
Good	280 (85.6)	47 (14.4)	1 (Reference)	
Average	180 (76.9)	54 (23.1)	1.35 (0.84-2.19)	
Poor	83 (75.5)	27 (24.5)	1.63 (0.91-2.93)	
Match period (time)				0.50
0-15 minutes	70 (76.9)	21 (23.1)	1 (Reference)	
16-30 minutes	84 (78.5)	23 (21.0)	0.79 (0.39-1.57)	
31-45 minutes	101 (82.8)	21 (17.2)	0.61 (0.3-1.27)	
46-60 minutes	92 (87.6)	13 (12.4)	0.48 (0.21-1.08)	
61-75 minutes	85 (79.4)	22 (20.6)	0.96 (0.46-1.98)	
76-90 minutes	99 (79.2)	26 (20.8)	0.87 (0.43-1.77)	
Extra time	12 (85.7)	2 (14.3)	0.54 (0.08-3.54)	

Player's position				0.73
Defender	173 (79.4)	45 (20.6)	1 (Reference)	
Midfielder	190 (79.8)	48 (20.2)	1.19 (0.71-1.99)	
Forward	142 (83.5)	28 (16.5)	0.87 (0.49-1.56)	
Goalkeeper	38 (84.4)	7 (15.6)	1.30 (0.13-13.31)	
Player's action with the ball				0.72
Dribbling	112 (83.6)	22 (16.4)	1 (Reference)	
Heading	46 (67.7)	22 (32.4)	1.54 (0.68-3.51)	
Deflecting the ball	199 (81.9)	44 (18.1)	1.04 (0.56-1.93)	
Kicking the ball	56 (86.2)	9 (13.8)	0.69 (0.28-1.7)	
Goalkeeper action	34 (85.0)	6 (15.0)	0.55 (0.04-7.66)	
No action with the ball	96 (79.3)	25 (20.7)	1.03 (0.46-2.31)	
Player's movement intensity				0.47
High intensity	456 (80.4)	111 (19.6)	1 (Reference)	
Low intensity	87 (83.6)	17 (16.4)	0.8 (0.44-1.47)	
Attention towards				0.41
Primary duelist	74 (87.1)	11 (12.9)	1 (Reference)	
The ball	435 (80.0)	109 (20.4)	1.68 (0.82-3.44)	
Team mate	24 (82.8)	5 (17.2)	2.11 (0.61-7.31)	
Other	10 (76.9)	3 (23.1)	2.53 (0.58-11.02)	
Involvement of a tackle				0.37
Yes	500 (80.8)	119 (19.2)	1 (Reference)	
No	43 (82.7)	9 (17.3)	1.52 (0.61-3.82)	
Involvement of foul play				0.02
No	194 (77.6)	56 (22.4)	1 (Reference)	
Yes	349 (82.9)	72 (17.1)	0.59 (0.38-0.93)	

a) Tackle analysis

Six hundred and nineteen of the 671 contact injury risk incidents involved a tackle and 119 (19.2%; 95%CI 16.1-22.3) of these incidents were linkable with an injury recorded in the injury surveillance. Figure 1 shows the percentages of contact injury risk incidents involving a tackle linkable with injuries (as defined in the FIFA post-match injury surveillance) for the tackle parameters direction, mode and action.

i. *Tackle direction*

Most (n=346) incidents resulted from tackles from the side, while 144 tackles came from the front and 129 tackles from behind. The differences in the proportions of contact injury risk incidents involving a tackle linkable with injuries compared with other contact injury risk incidents between the tackle direction categories (upper part of Figure 1), were not statistically significant (p=0.055).

ii. *Tackle mode*

The most common tackle mode in the incidents was on feet (n=328), followed by sliding in (n=176) and vertical jump (n=115). There were no statistically significant differences in the proportions of contact injury risk incidents involving a tackle linkable with injuries compared with other contact injury risk incidents-involving a tackle between the tackle mode categories (middle part of Figure 1).

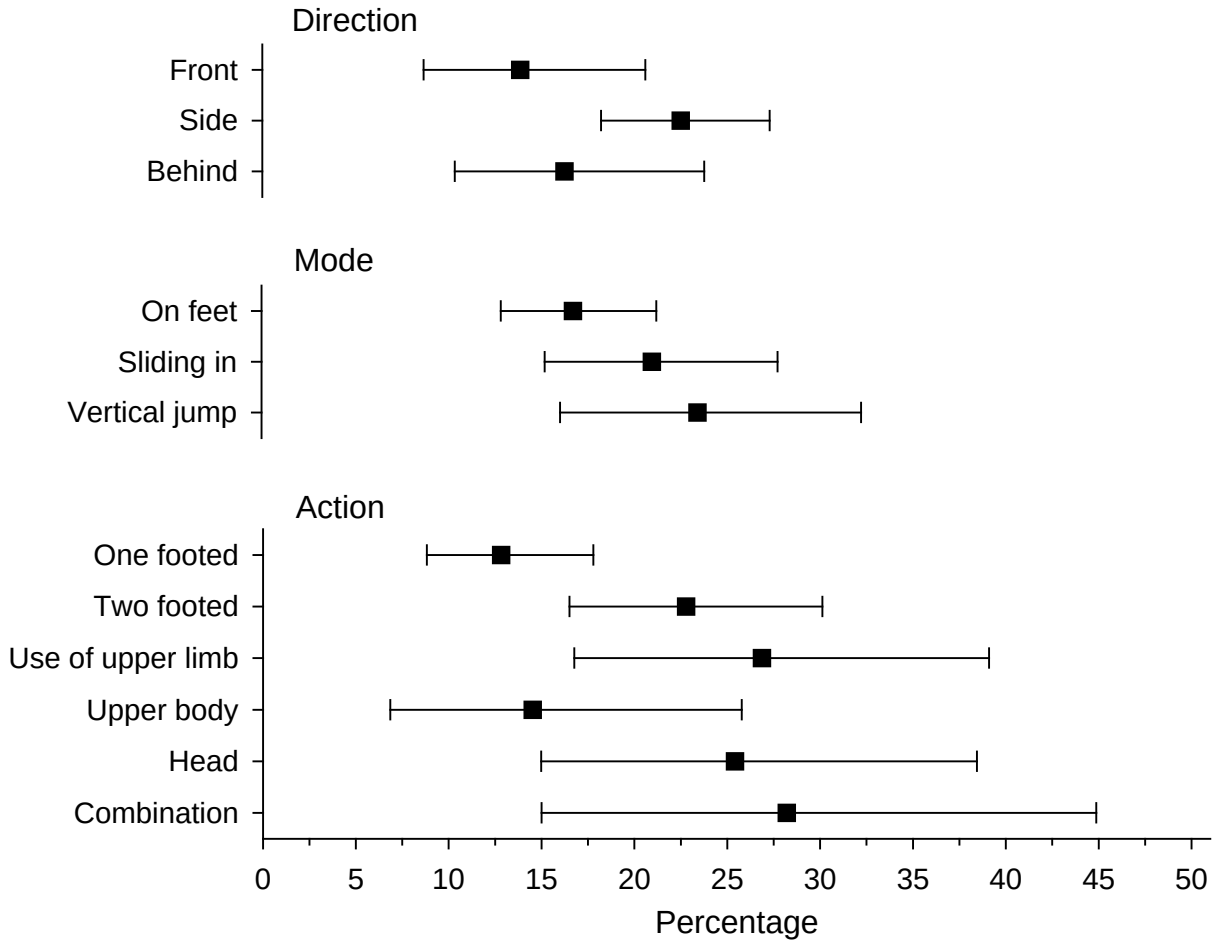

Figure 1 : The percentages and 95% confidence intervals of contact injury risk incidents involving a tackle that were linkable with injury for the different tackle parameters and categories.

iii. *Tackle action*

Most contact injury risk incidents involving a tackle, involved one footed tackle action (n=234), followed by two footed tackles (n=158), tackles involving use of the upper limb (n=67), tackles involving upper body contact (n=62) and tackles involving a clash of heads (n=59). Thirty-nine incidents involved a combination, and no dominant tackle action could be determined. Two-footed tackle actions, and tackle actions involving use of upper limb, a clash of heads or a combination of several tackle actions were more frequently associated with injuries than tackle actions involving upper body contact or one-footed tackle action. The differences in the proportions of contact injury risk incidents involving a tackle linkable with injuries compared to other contact injury risk incidents involving a tackle between the tackle action categories (lower part of Figure 1) were statistically significant (p=0.013).

IV. Discussion

The main finding of the present study was that there are major differences between the results obtained with the FIA methodology, the tackle analysis methodology and the injury surveillance system. In particular, the present study highlights some methodological issues concerning the definitions of some of the parameters used in the FIA methodology, which may be useful for developing new video-based epidemiological research methods for future studies of football injuries.

We were able to link only 42% of the contact injuries reported by team physicians with injury risk incidents, as defined in the FIA methodology and involving player-to-player contact. This questions whether the definition of an injury risk incident is appropriate for this type of epidemiological football injury study. In previous FIA studies, it was possible to link 34-54% of all reported injuries with injury risk incidents for both contact and non-contact injuries but with a tendency towards a higher identification percentage for contact injuries.[14, 18] In these FIA studies that combined medical data with video analysis of injury risk incidents, the injury definition used was based on time loss,[14, 16, 18] in contrast to the present study, which used a medical attention injury definition. The broader definition of injury used in the present study

may be a contributing factor for explaining the lower percentage of association achieved, as time-loss injuries are generally more serious and the circumstances of injury onset may be more visible in nature, and thus easier to detect and link to match events on video recordings. An investigation fo how injuries manifest themselves during matches could potentially provide useful information for a redefinition of what constitutes an injury risk incident. This view is supported by a previous study, which also found differences between the tackle mechanisms associated with injuries and those associated with FIA injury risk incidents.[26] These authors also questioned the validity of the current FIA injury risk definition.[26] A concern related to the low percentage of contact injuries recorded in the injury surveillance study that could be linked to contact injury risk incidents is that there may be one or more common but unknown factors linking these injuries that are not included in the FIA definition of an injury risk incident. It is thus difficult to consider the descriptive data obtained by these definitions as representing a general overview of playing actions and match circumstances leading to injuries. The present study considered all contact injuries as equal and did not differentiate between injuries of different types or different locations.

Injury risk incidents refer to situations in which the match is interrupted by the referee, a player is on the ground for more than 15 seconds, or the player appears to be in pain or receives medical treatment.[14, 16,18, 23, 29] However, these situations may have numerous other causes than an injury, such as player substitutions, off-sides or when a player is purely time-wasting. In the present study, some of these other situations were excluded, as only injury risk incidents resulting from contact between players were included in the analysis. It could also be questioned, whether apparent medical treatment (assessed on video recordings) should necessarily be associated with a risk of injury. A previous study by Fuller et al. indicated that most on-pitch medical attentions did not result in post-match physicians' reports, and that the majority of post-match physicians' reports were not associated with on pitch medical attention.[17]

Another concern with the FIA methodology is that the total frequencies of the variables and categories during a match are not assessed, making it impossible to draw conclusions with regards to the risk of injury associated with individual actions. Some factors, such as dribbling or a short pass may be present in most injury risk incidents, but they may also be the most common playing actions during a match; thus, an injury risk incident may result from only a small fraction of these actions. In the present study, the relative risk of injury associated with the variables was assessed by comparing the ratios of the number of contact injury risk incidents linked with contact injuries reported by team physicians to the number of contact injury risk incidents not linked with injuries for the categories of each variable. Using this approach, two variables were identified as independent predictors of injury; attack type and the involvement of foul play. Meaning merely, that the presence of some categories of the variables 'attack type' and 'foul play', during a contact injury risk incident, had an injury predictive value. Whether or not the variable itself has an injury predictive value remains unclear, as not all injuries could be linked with incidents and as the total frequencies of the variables were not recorded. However, the finding that the involvement of a foul in a contact injury risk incident was associated with a lower percentage of linkable injuries than when a foul was not involved seems somewhat counter-intuitive. A possible explanation for this result is that fouls usually result in the referee interrupting the game, which is one of the criteria for an FIA injury risk incident. In the present study most of the contact injury risk incidents involved a foul. However, player-to-player contact can cause injury irrespective of the involvement of a foul, and thus some non-foul contact situations, not fulfilling the criteria for a FIA injury risk incident, were almost certainly excluded. The results of the tackle analysis of the present study share similar limitations, as the included tackles were chosen from the cohort of identified contact injury risk incidents, and thus many other tackles (and possibly some injuries resulting from these tackles) were again most likely excluded.

The injury surveillance methodology may also present a source of bias, which could contribute to the discrepancies observed between the data obtained by the different methodologies. The injury surveillance reporting data consists of post-match injury reports, where all the players' complaints that required medical attention during, or immediately after, the match should have been recorded. For the researcher aiming at linking a post-match reported injury to an event on video material, the time (minute) of the injury reported on the injury form may constitute the best lead to identifying the corresponding match event. However, in post-match conditions, the reported time of injury may sometimes be an approximation, which complicates the video analyst's work in identifying the injury event. This could contribute to the low percentage of injury reports that were linked to an injury risk incident

The present study did not take into account the frequencies of the different criteria used in the injury risk incident definition. Thus, we cannot draw conclusions on whether some of the criteria, for example when a player is receiving on-pitch medical treatment, are more frequently linkable with a FIFA injury than others.

Importantly, only eight of the nineteen variables included in the original description of FIA [16], were included in the present study. Therefore, we cannot draw conclusions about the relevance of the other variables previously included in the FIA methodology.

What can we learn from the present study? The FIA video approach for investigating injury risk associated withplaying actions and match circumstancesrequires further development. The optimal method may be to focus on a few well-defined playing actions,in order to assess their total frequencies during matches, and to assess the injury risk associated with these actions. This approach was successfully applied by Fuller et al. in studies on tackle parameters in football [15, 17, 22] and rugby union.[40] They identified some tackle parameters having a greater propensity for causing injuries than others.[15, 40] They concluded that an assessment of injury causation factors should therefore, differentiate between initiating events with a high frequency of occurrence and a low propensity for injury and those events with a low frequency of occurrence and a high propensity for injury.[15, 40] Also Drawer et al. stated that an effective risk management strategy begins with an estimation and evaluation of the risks associated with the activity.[38] By comparing the number of contact injuries, based on post-match injury reports [2], and the number of injuries that was linked with the tackles identified on video recordings in one of the tournaments (2000 Olympics), included in the tackle analysis study by Fuller et al.[15], we find that 96% (98/102) of all the contact injuries were linkable with the tackles, further indicating that their methodology was suitable. However, we do not know how reliable the linking of a match event, identified by a researcher from video recordings, to an injury, reported by the team physician, really is. Fuller et al. identified 8572 tackles from 123 matches,[15] giving an average of roughly 70 tackles per match (or more than one tackle every two minutes).Thus, one player could potentially be involved in several tackles during the same match and within a short time frame. Considering this, the reliable linking of an injury to a specific tackle may be debatable, as it is based on the researcher's interpretation, especially when it comes to minimal and mild injuries.

V. Conclusions

In conclusion, the limitations discussed above make comparison of the results obtained by these three methodologies difficult to interpret and there is little evidence that the current definition of an injury risk incident, as defined in the FIA methodology, is adequate for linking match events with injuries. Future studies are needed that will provide more reliable methods for identifying injury causation events using video recordings: this is difficult, but it remains the most important factor. One potentially valuable methodological revision would be to include post-match reviews of video recordings of matches, in the presence of the injured player and/or the team physician who made the post-match medical assessment of the injured player, as these individuals are best suited to identify the injury events associated with an injury.

VI. Acknowledgments

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a) Contributorship statement

JR coordinated the study, conducted the statistical analysis together with HK, and drafted the manuscript. LL reviewed all the video recordings. JR, LL, LP, JK and MB participated in the study design, through revision and by partly writing the research plan, as well as approving the final manuscript. Author LP played a key role in the collection of injury data. JK, MB and LP participated in revision and writing of the research plan, the first draft, and the final manuscript. CF participated through revision and writing of the final version of the manuscript.

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