Technical University of Munich

TUM School of Medicine and Health

Prevention of Injuries in the German Football Bundesliga

Louis Iulius Leventer

Complete reprint of the dissertation approved by the TUM School of Medicine and Health of the Technical University of Munich for the award of the

Doktor der Philosophie (Dr. phil.)

Chair:

Prof. Dr. Joachim Hermsdörfer

Examiners:

1. Prof. Dr. Martin Lames
2. Prof. Dr. Tim Meyer

The dissertation was submitted to the Technical University of Munich on 22 November 2023 and accepted by the TUM School of Medicine and Health on 23 April 2024.

Acknowledgments

First and foremost, I would like to thank my supervisor, Prof. Dr. Martin Lames. Without him, I would not be here today. I would like to thank all the scientists who helped me through this research project, particularly Dr. Frida Eck at the Faculty of Health Science at Lund University. Finally, I want to thank my wife and mother, who pushed me to finish my PhD at tough times after I left the university.

List of Contributors

Sebastian Hofstetter:
Faculty of computer science, Technical University of Munich

Dr. Frida Eck:
Faculty of Health Science, Lund University

Dr. Matt Dicks:
Faculty of Sport Health and Exercise Science, University of Portsmouth

Dr. Ricardo Duarte:
Faculty of Sport and Health Science, University of Lisbon

Prof. Dr. Duarte Araujo:
Faculty of Sport and Health Science, University of Lisbon

Prof. Dr. Keith Davids:
Faculty of Sports and Exercise Science, Sheffield Hallam University

Prof. Dr. Martin Lames:
Faculty of Sports and Health Science, Technical University of Munich

Abstract of Dissertation

This text is part of the doctoral thesis at the Technical University of Munich. The thesis has two aims. The first aim is to improve insight into injury patterns and risk factors predisposing first-division Bundesliga football players. The second aim is to enhance theoretical knowledge of the mechanism leading to contact injury in team sports. Study 1 describes the overall injury pattern and investigates risk differences among playing positions. Study 2 investigates the risk differences that players possess in different season periods. Study 3 offers a theoretical rationale to investigate how contact between opponent players can lead to injury. Results from the epidemiological studies (Study-1 & Study-2) indicate significant differences in injury risk in both playing positions and periods throughout a football season. Results from Study 1 indicate significant differences in injury risk across playing positions. Specifically, wing defenders had a lower rate of groin injuries compared to forwards, with a rate ratio of 0.43 (95% CI: 0.17-0.96). Additionally, wing midfielders experienced the highest rate and burden of match-related injuries, while central defenders showed a similar trend in training injuries. Significate variations were observed across the periods of the season for match and training injuries. IRRs in matches was 1.30 (95% CI: 1.11–1.53) times higher in Q3 and 1.53 (95% CI: 1.31–1.78) higher in Q4 compared to Q1. For training injuries, IRR peaked in Q1 and Q3 followed by a marked decrease in each subsequent quarter. Compared to Q4, IRR was 1.62 (95% CI: 1.40–1.86) times higher during Q3 and 1.78 (95% CI: 1.53–2.07) times higher in Q1.

Contents

List of Figures

List of Tables

1 Introduction

Football (association soccer) is the most popular sport in the world, with over 38 million registered male and female players playing the game worldwide [1]. At the professional level, the main goal of a football club is success on the pitch. Success is intrinsically linked to state-of-the-art facilities and support mechanisms, as well as talented, physically and mentally conditioned, and healthy players. However, the risk of sustaining an injury, especially professionally, is substantial. Since professional football players are employees, their injury risk was 1,000 times higher compared to high-risk industrial occupations like construction and mining [2]. Injuries are associated with subsequent more severe re-injury [3–5], the early end of career [6–9] and even disability (e.g. early onset of osteoarthritis) after a sporting career [10–15].

1.1 German Premier League (Bundesliga) structure

The German football league "Bundesliga" is one of the world's most prominent and exciting leagues. It has the highest number of spectators per game among the five most significant European leagues [16]. According to Statista [16], the average number of spectators per game in the 2018-19 season was 43,500. For comparison, the average number of spectators per match in the English Premier League was 38,200, and in the Spanish La-Liga, 26,800 in the same season [16]. According to the UEFA coefficient, the German Bundesliga has the highest number of goals per game. As of the season 2021-22, on average, 3.12 goals were scored per match in the German Bundesliga, with corresponding values of 2.87, 2.82, 2.81 and 2.50 goals per match scored in Italian Serie A, followed by the English Premier League, France Ligue 1, and Spanish La-Liga correspondingly [17].

Founded by the "Deutscher Fußball Bund" in 1962 in Dortmund, the Bundesliga comprises 18 clubs. Two divisions constitute it. In the first division of the Bundesliga (1BL), the competitive season includes 34 league matches and runs from August to May, with most games played on Saturday and Sunday. Each club plays against each other, once at home and once away. The pre-season starts in early July, while the winter break commences from late December until mid-January (with inter-seasonal variations depending on the schedule of international tournaments). All of the Bundesliga clubs in the first and second divisions qualify automatically for the DFB Cup, which runs from August until June, and the winner of the Cup qualifies for the DFL Supercup against the Bundesliga champion. The top three clubs on the final league table qualify automatically for the UEFA Champions League group phases. At the same time, the fourth-place team enters the Champions League in the third qualifying round.

1.2 Media coverage in the German Football Bundesliga

The Bundesliga, particularly the 1BL, receives extensive media coverage. Satellite networks broadcast matches to over 200 countries worldwide. Off the pitch, journalists regularly attend pre- and post-match press conferences. Journalists and Scouters routinely observe training sessions and take part in press conferences either on club playing grounds or when clubs are training away from home. They do so even during winter break when clubs relocate to warm-weather countries for training. In addition, clubs provide media information on a regular basis.

1.3 Rationale for Study Settings

Football (Association Football) at a professional level is a complex sport that involves a considerable injury risk associated with a significant economic burden (e.g., a first-team player injured for one month costs the club around €500,000) and reduced success on the pitch [18]. Following a musculoskeletal injury, an athlete may be prone to enter a vicious cycle known as the continuum of disability [48]. The continuum of disability model postulates that tissue damage with longstanding rehabilitation following an injury may result in reduced functional performance due to poor sensorimotor control and, hence, increased susceptibility to another injury in a cyclic manner. Researchers postulate that an interplay between structural factors (e.g., damage to the mechanoreceptors of the affected ligament and associated tissues) and psychological factors (e.g., fear of re-injury) causes this reduction in movement control. Hence, an injury may result in reduced performance and increased risk for new injuries due to effects on physical, structural, and psychological functions. Epidemiological evidence supporting these ideas indicates that the most critical risk factor for injury is a previous history of one [19] and that Minor injuries of the same type and locality cause severe injuries. [20].

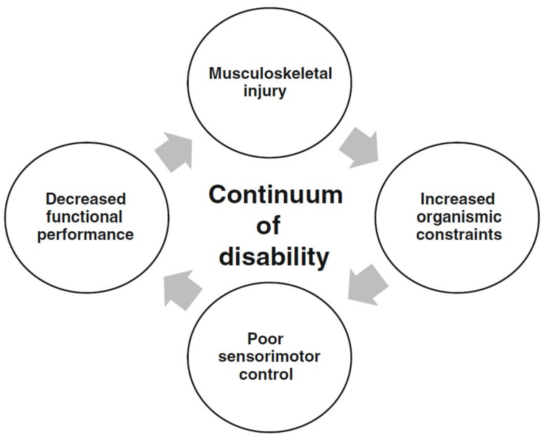

Figure 1.1: Continuum of Disability Model adopted from Wilkstrom et al.[21]

The main goal of prevention is to prevent players from entering the continuum of disability cycle to which an injury may predispose them. Van Mechelen's [22] model proposed that an in-depth epidemiological overview of injury incidence and severity is required to provide preventive measures for sports injuries. At the professional league level, epidemiological studies (mainly Scandinavian) show injury incidence rates of 16.1–28.2 match injuries and 2.0–11.8 training injuries per 1000 hours of match and training exposures, respectively [23–25].

Research indicates that regional differences in injury incidence due to playing style, intensity, and climate play an important role in shaping injury characteristics [26, 27]. For example, an audit showed a significantly higher overall injury incidence of traumatic and overuse injuries but lower rates of anterior-cruciate-ligament injury among professional teams from northern Europe with mild summers and cooler, temperate winters compared to more southern teams with a Mediterranean climate [27]. Therefore, to implement preventive measures for a specific target population, exploring that particular population injury pattern as a first step may be helpful.

1.4 List of publications

Papers:

[50] L. Leventer et al. "Injury patterns among elite football players: a media-based analysis over 6 seasons with emphasis on playing position". In: *International journal of sports medicine* 37.11 (2016), pp. 898–908.

[94] L. Leventer, F. Eek, and M. Lames. "Intra-seasonal variation of injury patterns among German Bundesliga soccer players". In: *Journal of science and medicine in sport* 22.6 (2019), pp. 661–666.

[107] L. Leventer et al. "Emergence of contact injuries in invasion team sports: an ecological dynamics rationale". In: *Sports medicine* 45 (2015), pp. 153–159.

[108] J. Ryynänen et al. "Combining data from injury surveillance and video analysis studies: an evaluation of three FIFA World Cups". In: *Global Journal of Medical Research* 14.3 (2014), pp. 1–9.

Conference proceedings:

[109] L. Leventer, F. Eek, and M. Lames. "Inter-seasonal Dispositions of Injury-risk Among First Division Bundesliga Soccer Players". In: *Poster presented at the 5th World Congress in Science and Soccer.* 2017, p. 178.

[110] L. Leventer, F. Eek, and M. Lames. "Poster presentation 2017 Intra-seasonal Dispositions of Injury-risk Among First Division Bundesliga Soccer Players". In: *Poster presented in part of TUM academic year celebration*. 2017.

[111] L. Leventer, G. Schauberger, and M. Lames. "Poster presentation 2018 - Preseason preventive effect on in-season (Re) Injury-risk in German Bundesliga Football Players". In: *Poster presented in part of TUM academic year celebration*. 2018.

[112] L. Leventer, F. Eek, and M. Lames. "Injury patterns amoung elite football players: A media-based analysis of over siz seasons with emphasis playing position". In: *Book of Abstracts of the 21st Annual Congress of the European College of Sport Science Vienna Austria*. European College of Sport Science. 2016, p. 566.

[113] L. Leventer, F. Eek, and M. Lames. "Intra-seasonal Dispositions of Injury-risk Among First Division Bundesliga Soccer Players". In: *Book of Abstracts the 5th World Congress in Science and Soccer.* 2017, p. 320.

[114] L. Leventer. “Do we really need zero-inflated models in the analysis of injury-risk?” In: *Innovation und Technologie im Sport*. 2017, p. 124.

1.5 Summary of papers

Paper-1 Abstract:

Background and objective:
Football injury research relies on systematic data collection from club medical teams, which provides the highest quality information. However, clubs' reluctance to share data creates research challenges, making it difficult to identify injury trends and develop prevention strategies. In high-profile leagues like the Bundesliga, media-based surveillance could be an alternative, though its reliability and validity are unproven. Each football position has distinct traits and injury risks. Defenders are prone to head injuries from aerial duels, while midfielders face muscle and tendon injuries due to extensive running and directional changes. However, data on injury risks across positions in the Bundesliga is scarce. This study aims to: 1) assess the reliability of a media-based injury system for research in the Bundesliga, and 2) describe injury patterns and risk differences across playing positions.

Methods: Exposure and injury data from 1448 players over 6 consecutive seasons (2008-2014) were collected from a media-based register (transfermarkt.de). Two separate independent sources were used to affirm transfermarkt.de reliability and validity. Regression analysis was used to retrieve incidence rate ratios among playing positions.

Results: To ensure reliability, we analyzed 330 random cases. The inter-observer agreement was 91.1%, which corresponds to a Cohen's Kappa value of 0.82. We found significant differences in injury rates based on playing positions. Specifically, wing defenders had a lower rate of groin injuries compared to forwards, with a rate ratio of 0.43 (95% CI: 0.17-0.96). Additionally, wing midfielders experienced the highest rate and burden of match-related injuries, while central defenders showed a similar trend in training injuries.

Conclusion: Without a prospective surveillance system, especially for severe injuries, a media-based public register could be a viable alternative. Injury risks and patterns vary significantly between playing positions.

Author contribution:

Louis Leventer write the first draft of the paper which was critically revised and approved by all authors. Louis Leventer developed the study design, prepared the data for analysis, carried the analysis, and wrote the manuscript. Dr. Frida Eck aided with study design and data quality control, Checked the analysis and provided remarks in drafting the manuscript. Sebastian Hofstetter retrieved the data from transfermarkt.de. Prof. Dr. Martin Lames aided with study design, contributed to the interpretation of the findings, provided remarks in writing the manuscript.

Paper-2 Abstract:

Background and objective:
Significant fluctuations in injury risk have been observed throughout the football season. Given that seasons are divided into periods with consistent loads and intensities, we examined injury risk across these periods, unlike previous studies that used a month-based approach. This method aligns with the principle of periodization, where players train according to structured phases, making it a more accurate reflection of training and match demands.
Methods: Regression analysis was implemented across six consecutive seasons of German Bundesliga, divided into six periods each: Pre-season (PS), winter-break (WB), quarter 1–4: (Q1–Q4).
Results: Significant variations in injury-risk were observed for match and training injuries. IRRs in matches was 1.30 (95% CI: 1.11–1.53) times higher in Q3 and 1.53 (95% CI: 1.31–1.78) higher in Q4 compared to Q1. For training injuries, IRR peaked in Q1 and Q3 followed by a marked decrease in each subsequent quarter. Compared to Q4, IRR was 1.62 (95% CI: 1.40–1.86) times higher during Q3 and 1.78 (95% CI: 1.53–2.07) times higher in Q1.
Conclusions: The rise in match IRRs towards the end of the season suggests that coaches should prioritize recovery during this period. Additionally, training injuries appear to have a carry-over effect. Future research should explore how preparatory phase training can be optimized to prevent injuries during the competitive season.
Author contribution: Louis Leventer write the first draft of the paper which was critically revised and approved by all authors. Louis Leventer developed the study design, prepared the data for analysis, carried the analysis, and wrote the manuscript. Dr. Frida Eck aided with study design and data quality control, provided remarks in writing the manuscript. Prof. Dr. Martin Lames aided with study design, provided remarks in writing the manuscript.

Paper-3: Abstract:

The incidence of contact injuries in team sports is significant, and understanding injury mechanisms is crucial for adopting preventive measures. In football, evidence shows that most contact injuries occur during one-on-one interactions. However, previous studies often report injury mechanisms in isolation, lacking a theoretical explanation of how injuries arise from player interactions. This position paper proposes an ecological dynamics framework to enhance the understanding of behavioral processes leading to contact injuries in team sports. Based on research highlighting performer-environment interactions, contact injuries are suggested to result from symmetry-breaking processes during on-field interactions among players and the ball. This approach considers control parameters that may provide insights into the information sources players use to reduce contact injury risk. Clinically, an ecological dynamics analysis could help sport practitioners design training sessions based on selected parameter thresholds as primary and secondary preventive measures during training and rehabilitation.

Author contribution: Louis Leventer write the first draft of the paper which was critically revised and approved by all authors. Louis Leventer wrote the manuscript. All co-authors provided critical remarks and participated in correcting manuscript drafts.

2 Background

In 1992, Van Mechelen introduced the sequence of injury prevention model as a framework for alleviating sports injuries [22]. The model comprises four steps. The first step outlines the severity and incidence rate of injuries. In the second step, risk factors and injury mechanisms are distinguished. Equipped with the insight of the preceding steps, one introduces a preventive measure in the third step. In step four, the preventive effect of the new measure is verified by re-measuring the current injury severity, thus repeating step one of the model recursively. This model was further extended in 2006 by Finch [32]. In the revised model Translating Research into Injury Prevention Practice, two steps were added to emphasize that only interventions adopted in real-life sports settings are suitable for preventing injuries. In step five, the focus is on describing the intervention context. Step six aims to implement the intervention in a real-world setting and evaluate its effectiveness.

The thesis focuses mainly on the first but also the second step in the prevention sequence by evaluating potential extrinsic risk factors (playing position and period of season) for injury. In the second step, a theoretical rationale for gaining insight into the mechanism leading to contact injuries is articulated.

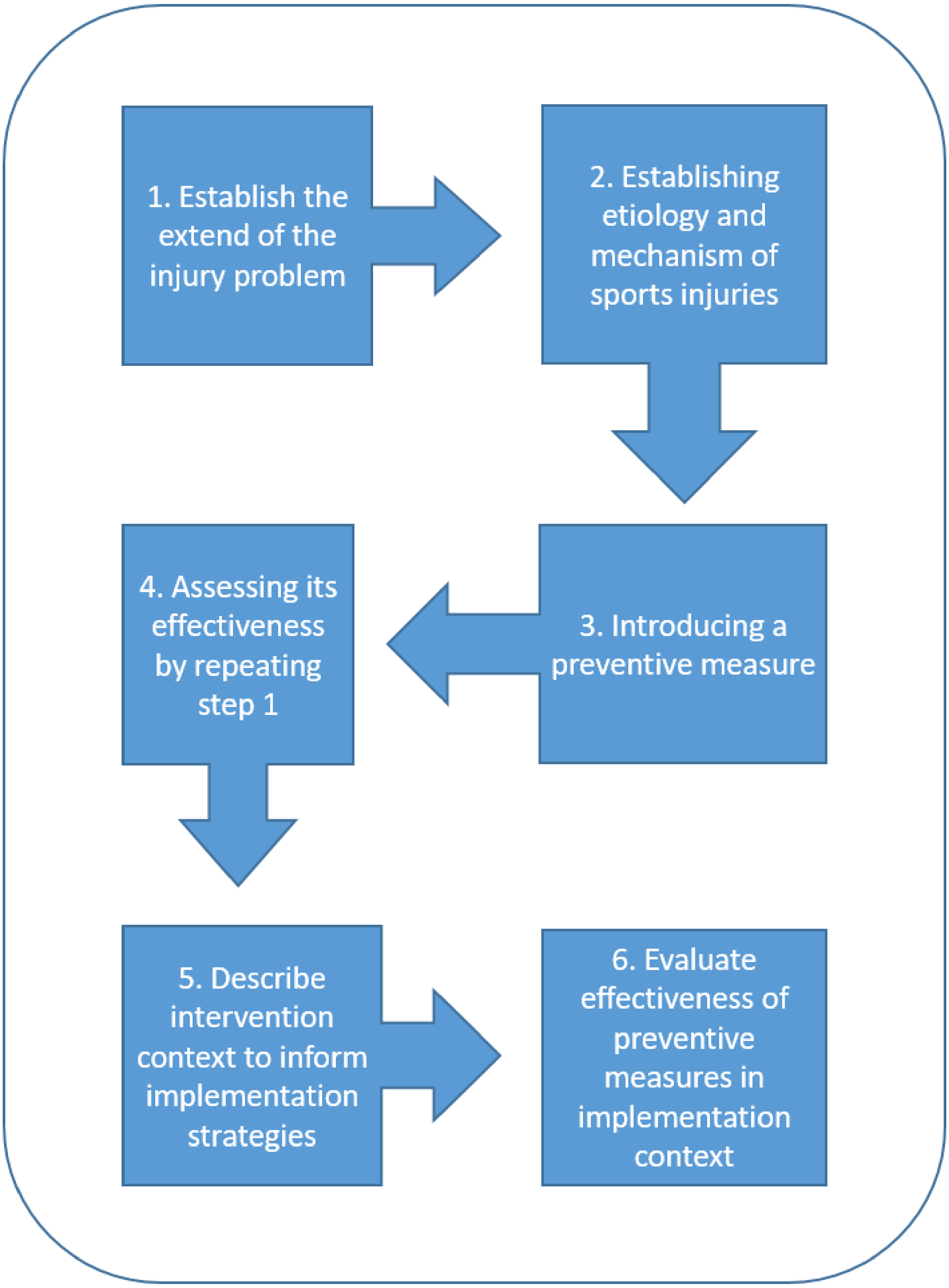

Figure 2.1: van Mechelen [22] and Finch [32] Injury Models

2.1 Injury surveillance

Injury surveillance is an essential management tool epidemiologists rely upon for identifying risk factors and introducing preventive measures [30, 33, 34]. Since, at an elite level, athletes have direct contact with the medical team, injuries have been recorded by medical personnel. This approach has been considered the gold standard for injury surveillance and recommended as an established method in the consensus statement guidelines of methodological issues in football injuries studies [31].

Ekstrand et al.[79] highlights several key points that underscore the value of medical staff reports:

1. **Accuracy and Reliability**: The data collected by medical staff is based on direct clinical observations and assessments, ensuring a high level of accuracy and reliability. This is crucial for making informed decisions about player recovery and return-to-play (RTP) timelines.

2. **Comprehensive Data Collection**: Medical staff are able to capture a wide range of injury details, including the type, severity, and context of injuries. This comprehensive data collection is essential for understanding injury patterns and developing effective prevention strategies.

3. **Clinical Judgment**: The study emphasizes the importance of clinical judgment in determining the duration of absence and RTP decisions. Medical staff use their expertise to assess the player's condition and make informed decisions about their readiness to return to play.

4. **Consistency Across Studies**: By using standardized forms and methodologies, the study ensures consistency in data collection across different teams and seasons. This consistency is vital for comparing results and drawing meaningful conclusions from the data.

5. **Evidence-Based Guidelines**: The study provides evidence-based guidelines for expected time away from training and competition for the most common injury types. These guidelines are invaluable for medical and coaching staff in planning training and team composition.

Overall, Ekstrand's study [79] demonstrates that medical staff reports are essential for accurate and reliable injury surveillance. Their clinical expertise and direct involvement in player care make them the gold standard for injury data collection and analysis. However, routine implementation of prospective injury surveillance systems requiring clubs to send medical information to third parties may pose some real difficulties for two main reasons. First, there is a risk that medical data will get into the hands of untrusted sources. If clubs are to send confidential medical information routinely outside their environment, a whole management system should be put in place to ensure this data's confidentiality. Second, from a club perspective, the entire organization needs a comprehensive implementation of an injury surveillance system, which will likely place an additional burden on the club, specifically on the medical team. None of Europe's most prominent leagues has a medical prospective injury surveillance system operating routinely. That is, of the kind in which clubs regularly send injury and exposure data to outside sources (i.e. outside the club) to perform scientific investigations. Researchers studying injury patterns either collect injuries from their access to the club (often being part of the medical team) or rely on alternative data sources and methods for surveying injuries.

Some additional purposes of injury recording in football include:

1. **Trend Analysis**: Injury recording helps in identifying trends over time, such as the most common types of injuries, their frequency, and the periods when they are most likely to occur. This information can be used to develop targeted prevention strategies.

2. **Performance Impact**: By analyzing injury data, teams can assess the impact of injuries on player performance and team outcomes. This can help in making informed decisions about player rotations, rest periods, and training loads.

3. **Resource Allocation**: Injury data can guide the allocation of medical and training resources. For example, if a particular type of injury is prevalent, teams can invest in specific rehabilitation equipment or hire specialists to address that issue.

4. **Policy Development**: Injury recording can inform the development of policies and guidelines for player safety. This includes rules for safe play, equipment standards, and protocols for injury management and return-to-play decisions.

5. **Research and Innovation**: Detailed injury records provide a valuable dataset for scientific research. Researchers can use this data to study the mechanisms

of injuries, evaluate the effectiveness of prevention programs, and develop new treatment methods.

6. **Insurance and Legal Purposes**: Accurate injury records are essential for insurance claims and legal matters. They provide documented evidence of injuries, treatments, and recovery processes, which can be crucial in disputes or claims.

7. **Player Education**: Injury data can be used to educate players about the risks associated with their sport and the importance of injury prevention and proper rehabilitation.

By considering these additional purposes, injury recording becomes a comprehensive tool that not only aids in immediate injury management but also contributes to the long-term health and performance of athletes.

2.2 Injury surveillance: Is medical data the gold standard?

The validity and reliability of data collection using a prospective injury surveillance system had been reported in very few studies in sports [35, 36]. For the most part, the data seem to be trustful and complete because a study instruction manual has been provided to clubs' or federations' medical teams agreeing to participate in a study [37]. However, validity studies indicate that the medical teams fail to identify or report a considerable portion of injuries [38, 39]. The extent to which injuries are identifiable and reported varies considerably depending on the type of sport and level of play. Among World Cup Alpine skiers and snowboarders, 91% of injuries were identifiable through retrospective athlete interviews compared with only 47% by medical personnel [40]. These significant differences in identifying injuries can be partly attributed to skiing being an individual sport, where the medical team does not have frequent contact with athletes and seeing athletes on a daily basis, making the likelihood of identifying and hence documenting injuries exceptionally high.

Conversely, in elite professional football, especially in male professional football leagues, the medical team is present in most training sessions and matches. However, discrepancies in reporting injuries are nerveless present. Bjorneboe reported that prospective injury surveillance by medical staff underestimated time-loss injuries by at least one-fifth compared with player interviews [38]. In professional female football, the medical staff missed reporting more than half of all injuries occurring during the follow-up time (7-month season) [41]. Specifically, the medical team reported only 44% of all match injuries, with equal reporting rates across the whole teams participating, suggesting that the lower reporting was not due to a specific club(s) failing to comply with protocol [41].

The reluctance of soccer clubs to share injury data poses a significant challenge for conducting comprehensive injury research. This unwillingness stems from concerns over player privacy, competitive advantage, and potential legal issues.

Ethical aspects

- Player Privacy: Sharing detailed injury data can compromise the privacy of players. Medical information is sensitive, and there are ethical concerns about how this data is used and who has access to it. Ensuring that players' personal health information is protected is paramount.

- Consent: Players must give informed consent for their medical data to be shared. Without proper consent, sharing this data can lead to ethical and legal complications.
- Data Security: There are risks associated with the storage and transmission of medical data. Ensuring that data is securely handled to prevent unauthorized access is a significant ethical concern.

Competitive advantages

- Strategic Information: Injury data can reveal a team's vulnerabilities. Opponents could exploit this information to gain a competitive edge, such as targeting a recently injured player or adjusting their tactics based on the injury status of key players.
- Confidentiality: Clubs may want to keep their injury data confidential to maintain an element of surprise and prevent opponents from gaining insights into their squad's fitness levels and potential weaknesses.
- Market Value: The injury history of players can affect their market value. Clubs might be reluctant to share data that could devalue their players in the transfer market or affect contract negotiations.

These factors contribute to the complexity of sharing injury data in soccer, highlighting the need for careful consideration of ethical standards and competitive dynamics. Without access to detailed and accurate injury data, researchers face difficulties in identifying injury trends, understanding the mechanisms behind injuries, and developing effective prevention strategies. This lack of data hampers the ability to improve player safety and optimize training and rehabilitation programs. Consequently, the gap in data sharing limits the progress of injury research and the implementation of evidence-based practices in soccer.

Given these concerns, additional methods for surveying injuries were investigated as potential alternatives [39]. Web-based applications, text messaging-only and text messaging-phone-medical examination methods for injury surveillance were compared [41–43]. Results show an impressive improvement in reporting of injuries by these contemporary surveillance methods compared to a medical-only traditional surveillance system. However, special care should be taken since the settings these surveillance systems were tested in were either at youth level [41] or elite (professional) female players [42]. Due to financial limitations, youth players, female players and players in sub-elite levels have restricted access to medical attention in a club. Limited access to a club medical team may result in a lower rate of reported injuries since skilled personnel are unavailable for most of the training sessions and/or matches played, which increases the likelihood of unidentified and, hence, misreporting injuries in this target group.

An alternative method for assessing injuries could involve leveraging data from mass media sources. Retrieving injury data based on media reports might be a sound alternative in prominent leagues. As previously mentioned, one might use media presence at matches and training. In recent years, an increase in the number of studies investigating injuries based on media sources has been evident. However, this method suffers from some limitations as well. The high risk of selection bias is particularly likely to be a limitation. It is plausible that journalists will cover particular (e.g. more successful) clubs, leagues and even prominent players, hence providing more (and more precise) injury reports compared to other clubs, leagues or players, which receive less attention from the media. Besides, when adopting a surveillance system based on mass media, particular attention should be drawn since injury data is expected to be somewhat incomplete. That is, injuries of minimal severity, which do not cause a significant absence of players participating in football activities are potentially underestimated since journalists are likely to be unaware of a player suffering from such an injury.

Table 2.1 outlines recent studies in which researchers relied upon mass media to conduct epidemiological research on injury risk in professional football.

Author (year)	Sample	Media source	Reliability assessed	Main Findings
Aus der Fünten., (2023)[116]	German football players during 7 seasons	The Kicker Magazine and other web sources	Unreported	Incidence-rate of injury and injury pattern.
Falese et al., (2016) [45]	Italian Serie-A 286 players	`http://www.footnall-lineups.com`	Unreported	Injury pattern
Falese et al., (2020) [46]	Italian Serie-A players	`www.transfermarkt.de`	Unreported	ACL Incidence-rate and ACL Injury patterns.
Forsythe et al., (2021) [54]	Data from UEFA leagues between 1999 and 2019	`transfermarkt.co.uk`, `uefa.com`, `fifa.com` and other webpages	Unreported	ACL injury patterns.
Grassi et al., (2020) [51]	Data from 12 seasons	`www.transfermarkt.de`	Unreported	Achilles tendon injury patterns.
Grassi et al., (2022) [48]	Italian Serie-A during 11 seasons	`www.transfermarkt.com`	Unreported	Achilles injury incidence-rate and injury patterns.
Krutsch et al., (2020) [128]	German football players during 9 seasons	The Kicker Magazine	Unreported	ACL injury incidence-rate and injury pattern.
Niederer et al (2018)[49]	Top leagues in Europe	`www.transfermarkt.dewww.whoscored.com`	Based on Leventer et al[50]	Significant shorter carrier duration after an ACL injury.
Lavoie-Gagne et al., (2022)[52]	major European soccer leagues between 2000 and 2016	`www.transfermarkt.de`	Unreported	Knee Meniscus injury patterns.
Lavoie-Gagne et al., (2021)[53]	major European soccer leagues between 2000 and 2016	`www.transfermarkt.de`	Unreported	Leg-fracture injury patterns.
Tazima Nittaet et al., (2021) [47]	Brazilian soccer players during 5 seasons	`www.transfermarkt.com.br`	Unreported	ACL Incidence-rate and ACL injury patterns.

Table 2.1: Epidemiological studies using a media-based register for the analysis of injuries in football

2.3 Injury definition

Apart from the type of surveillance system adopted, the definition of injury implemented can also significantly influence the reported injury rate [55]. The definition of injury was revised numerous times. The National Athletic Injury Registration System (NAIRS) defined an injury as reported if it limits athletic participation for at least the day after the day of the onset [56]. The injury definition of the Council of Europe requires that an injury has at least one of the following characteristics: 1) a reduction in the amount of level of sports activities, 2) a need for (medical) advice or treatment, and 3) adverse social or economic effect [30]. Others recommended that injuries with a diagnosis using non-medical jargon should be excluded and only injuries whose treatment goes beyond ice and bandaging should be included [57]. However, using this approach was criticized [58] as it would exclude minor injuries, which could hide the causes and onset of chronic, more severe injuries such as osteoarthritis.

The consensus statements on injury definition and data collection procedures for football injuries studies define an injury as any physical complaint (caused by a transfer of energy that exceeded the body's ability to maintain its structural or functional integrity) sustained by a player during a match or training, irrespective of the need for medical attention or time loss from sports activities [31]. It is essential to recognize that the consensus paper provides not only one but three different definitions of an injury: any physical complaints, medical attention injury, and time loss definition. An injury that results in the player receiving medical attention is referred to as a medical-attention injury. Consequently, an injury resulting in a player being unable to participate in future training or match play is referred to as a time-loss injury. The choice of which injury definition to implement can significantly influence the rate and characteristics of injuries collected. Players will only sometimes seek medical attention for physical complaints; even fewer cases will result in time-loss injuries. Therefore, it was hypothesized that a "physical complaint" definition would yield a higher injury rate than a "medical attention" definition, with a "time loss" definition resulting in even lower injury rates [58].

There are several reasons for choosing the time-loss criteria within a professional setting, as in 1BL. One is, as recognized by the consensus paper that variation in medical support may create differences in the incidence of injury reported between studies. Players frequently complain of physical problems, and without the daily presence of the medical team, many of these complaints will go unrecorded. Adopting a time-loss injury definition in an environment that constantly monitors players' health, as in male elite football, allows for capturing the most relevant injuries, those that directly influence players' ability to participate in training or match play.

However, time-loss injury criteria also have some clear limitations. A "time-loss" definition would only capture the worst injuries, the so-called tip-of-the-iceberg phenomena. As previously stated, the viability of embracing a "time-loss" criteria might be high for a sport which is primarily characterized by acute traumatic injuries. However, many overuse injuries are not captured if a "time-loss" definition is used to record injuries [29]. Football is not primarily a technical sport, but a physical one in that situations involving contact between opposing players are of great majority [18]. Overuse injuries in football make up a considerable portion of injuries, with evidence indicating an increased incidence rate throughout the years [59]. Therefore, the feasibility of using time-loss injury criteria for recording overuse injuries has been questioned [29]. Of the three injury definitions, it was suggested that the "any physical complaint" and "medical attention" definitions are the most appropriate [29]; however, apart from exceptional cases such as conducting studies in settings comprised of short-duration tournaments, these definitions are rarely used in sport injury research. The inability to accurately estimate the onset of chronic overuse injuries is a significant concern. Symptoms progress gradually, and players are likely to delay medical attention until reaching a certain point where pain is not perceived to be tolerable any longer. In a prospective cohort study among 12 athletes followed from one season, a "time-loss" injury criteria captured only 1 out of 8 episodes where players suffered from significant pain and reduced functionality [58]. Based on these findings, various recommendations were suggested, moving from recording injuries as such to assessing pain and potential functional loss instead [29]. It was suggested that valid and sensitive scoring instruments for detecting overuse injuries should be established. Subsequently, these instruments should be administered across a particular cohort to obtain a more complete insight into the extent to which pain and disability play. Furthermore, in adopting a "time-loss" criteria, players might choose to offset time loss by postponing rest until reaching the off-season or winter break period, which injury surveillance systems might not adequately cover during these periods (e.g., due to reduced media coverage).

A time-loss definition was implemented because player absence / unavailable ultimately influences key components at the professional level, such as coachability to work with a player in training and selecting the player line-up in match play. This decision must be kept in mind when interpreting findings.

2.4 Injury mechanism and severity

Injuries are typically divided into acute traumatic and chronic overuse injuries. Operational definitions typically define traumatic injury as an injury resulting from a specific, identifiable event and an overuse injury as one caused by repeated micro-trauma without a single, identifiable event responsible for the injury. The term gradual onset was also used to define an overuse injury [29, 58]. The majority (70%) of injuries in football are due to trauma, but almost one-third (30%) of injuries are due to overuse [60]. However, this dichotomy is somewhat arbitrary. Overuse injuries may emerge from a traumatic injury as much as a traumatic injury may emerge from an overuse injury [118–120]. An example is the onset of chronic ankle instability followed by repetitive ankle sprains caused by contact between opponent players (typically involving a foul play situation).

In compliance with the consensus statement [31], injury severity within this thesis is defined as the number of days that have elapsed from the date of injury to the date a player was indicated from the reports to return to full participation in team training, and availability to match selection (return-to-play). While the consensus statement provides a standardized methodology for recording and reporting injuries, it does not eliminate the need for clinical judgment in determining when a player has fully recovered. The methodology does not account for the underlying factors influencing the return-to-play (RTP) decision, which often involves a combination of clinical assessments, player feedback, and situational considerations. Therefore, while the consensus statement offers consistency in injury reporting, it is essential to recognize that clinical opinions remain critical in the RTP process [121].

The severity of the injury is typically defined in terms of the lay-off time a player sustained from the injury. The National Athletic Injury Illness Reporting System (NAIRS) categorizes injury severity between minor (less than 8 days), moderately severe (8 to 21 days) and serious injuries (over 21 days or permanent damage). However, despite differences in cut-off between studies, less than 1 week is considered minor, 1 to 4 weeks is considered moderate and more than 4 weeks of absence from football-related activities is considered severe [61]. Furthermore, van Mechelen recommended that the severity of sports injuries be described based on six criteria: nature of injury, duration and nature of treatment, sporting time lost, work time lost, permanent damage, and cost [61].

Others indicated that adhering to descriptive phases such as ’minor’, ’moderate’ and ’severe’ could be misleading because ’minor’ injuries, measured in terms of time loss, can involve significant tissue damage [62]. Alternatively, it might be preferable to define injury severity by the consequences of an injury rather than the injury per se. This can be defined as time loss from training/ competition for elite players, as implemented in the thesis. However, for sub-elite, amateur players van Mechelen [22] suggested that it would be more appropriate to use a broader definition that includes the time loss from sports participation together with the time loss from regular occupation (daily activities outside the sporting environment).

The severity criteria adopted within this thesis were divided into the following time intervals of absence from training and play: minimal injury (1-3 days), mild (4-7 days), moderate (8-28 days) and severe (more than 28 days).

2.5 Exposure and injury rate definitions

Injury incidence rates allow understanding the extent of the injury problem, which is the first step needed prior to designing a preventive measure [22].In order to determine the incidence rate of injuries, it is essential to record information related to the time a player was under risk [63]. Following the consensus statement, exposure is preferably recorded separately for match and training. Match exposure is defined as "play between teams of different clubs" and was recorded within the thesis as the number of minutes a player was reported to be playing in an official match (data retrieved from transfermarkt.de). Based on exposure records, the injury incidence rate can be calculated. Within the thesis, exposure was calculated separately for match and training injuries.

Data included the number of minutes a player had played was provided on an individual level (per player); this information was used as the denominator for calculating match injury incidence. Data indicating training time on an individual level (pre-player) is not available; therefore, for training and overall injuries (match and training injuries), person-time at risk is defined in study-1 in terms of player-season (1 player in the cohort for 1 season) and study-2 in terms of player weeks. The use of player-week or player-season is an application of the general epidemiologic concept of person-time at risk that is specific to sports injury epidemiology [64]. Following the recommendation indicated in the consensus statement [31] within this thesis, the injury incidence rate in matches was reported per 1,000 match-hours.

2.6 Injury incidence and characteristics in football

Table 2.2 outlines the incidence rate (IR) of injury reported in domestic leagues in men's professional football from recent studies. Within male senior elite (professional) players, the IR in domestic leagues varies greatly. Reports of IR indicated around 30 match injuries per 1,000 match-hours [65–67] and around 3.0 training injuries per 1,000 training hours [67, 68] with some extreme values of 62.0/1,000 match hours and 11.5/1,000 training hours reported in some leagues [69].

The incidence rate of injury was also monitored in senior male elite international tournaments such as the FIFA World Cup [70–74], and Olympic Games [75–78]. An analysis of injuries during the 2014 FIFA World Cup in Brazil indicates an IR of 50.8 injuries per 1,000 match-hours [73]. The extent of training injuries players sustained during this tournament was not reported.

Players are generally at a greater risk of injury during matches than in training. Injuries most frequently affect the lower limbs (85 – 90%). Of the lower limb, the sites of highest to lowest injury risk are the thigh, knee and ankle, which are in great majority attributed to overuse injuries. The overall incidence rate of sustaining a hamstring strain is 1.67 injuries / 1,000 hours. The risk of a hamstring strain is approximately sixfold higher in matches compared to training (6.47 in matches; 0.76 in training) [59].

Hamstring injuries constitute a quarter (25%) of all injuries, the single most common injury. The medical team in a club of 25 players can expect to encounter around six hamstring strains, resulting in around 90 days of absence and unavailability to 15-21 matches per season [79]. This injury load can be translated to an injury burden of around 28.8 days per 1,000 hours of total exposure [79]. Recurrence of hamstring strain is reported to range from 12 to 31% [80].

After lower limbs, the head and neck are the most frequently injured areas. The incidence rate of head injury ranges between 0.50 to 2.00 injuries per 1,000 player hours, with studies indicating an incidence rate of 0.02-0.56 concussions per 1,000 match hours [60]. The most common cause of head injuries identified from the video-based analysis was a head-to-head collision, mainly following a clearance of the ball by the goalkeeper transferring the ball to the far half of the pitch. This game situation typically invites opponent players to fight for ball possession with their head while the ball is above their height, increasing the risk of head collision and concussion. Most non-contact injuries were identified in match situations while players appear to be landing/jumping but also in cutting (pivoting) movements and sprinting [60].

Author (year)	Domestic league	Sample	Match IR / 1000h	Training IR / 1000h
Hassabi et al (2010) [69]	Iran 1st division	1-team followed for 4 months	62.0	11.5
Salces et al (2014) [81]	Spanish 1st 2nd division	16 teams (427 players) over 1 season	43.5	3.5
Reis et al (2015) [82]	Brazilian 1st division	1 team (48 players) followed 1 season	42.8	2.4
Stubbe et al (2015) [67]	Netherlands 1st division	8 teams followed for 1 seasons	32.8	2.8
Shalaj et al (2016) [68]	Kosovo 1st division	11 teams followed for 1 season	35.4	3.2
Fitzharris et al (2017) [65]	Ireland 1st division	6-8 teams (140 players); 1 season	23.1	4.8
Larruskain et al (2017) [66]	Spanish La-liga	1 team followed over 5 seasons	29.9	4.8
Bayne et al (2018) [83]	South-Africa	2 teams over 1-season	24.8	0.9
Eliakim et al (2018) [84]	Israel 1st division	1 team over 2-seasons	9.4	4.7
Smpokos et al (2019) [85]	Greece 1st division	123 players followed over 3-seasons	55.0	2.3
Jones et al (2019) [86]	English Premier League	10 teams followed for 1 season	24.4	6.8

Table 2.2 outlines recent studies incidence-rate values in which researchers used a prospective medical injury surveillance system for collecting injuries in professional football across variety of countries.

2.7 Risk factors for injuries in football

Injuries are indicated to emerge from an interaction of factors predisposing the player to risk. A model of injury causation was introduced by Meeuwisse et al. [87], which clearly distinguishes intrinsic and extrinsic risk factors. Intrinsic risk factors such as age, sex, previous injury, strength, flexibility and neuromuscular control are all identified as athlete-oriented. Extrinsic risk factors are indicated to reside outside the athlete. Shoe traction, floor friction (the subject matter of artificial turf in the prevention of injuries), protective equipment, laws of the game, and weather conditions are all examples of extrinsic risk factors. A central theme in the Meeuwisse et al. [87] model is what the authors call an inciting event, the event which causes an injury. Although a formal definition of what is an inciting event was not articulated, the authors state that the possession of intrinsic and extrinsic risk factors as such does not necessarily cause an injury; instead, risk factors only "prepare" or predispose the athlete for a given injury. The final link which causes the injury is a particular situation (indicated as a specific event). This particular situation has been proposed to emerge into an injury from an interaction between risk factors [87]. In other words, the constellation configuration of risk factors in a specific situation causes the injury. Recognizing the importance of understanding how risk factors interact, Bittencourt et al. [88]. recently proposed that if sports injury phenomena are to be understood, a paradigm shift, moving from identifying risk factors in isolation to uncovering how they emerge into an inciting event should be the focus of sports injury research. Borrowing from ideas in non-linear dynamical systems theory, the authors introduced tools that can shed light on how an inciting event emerges. However, as noted by the authors, epidemiological research investigating relationships in correlation and regression for identifying risk factors remains of great value for practitioners.

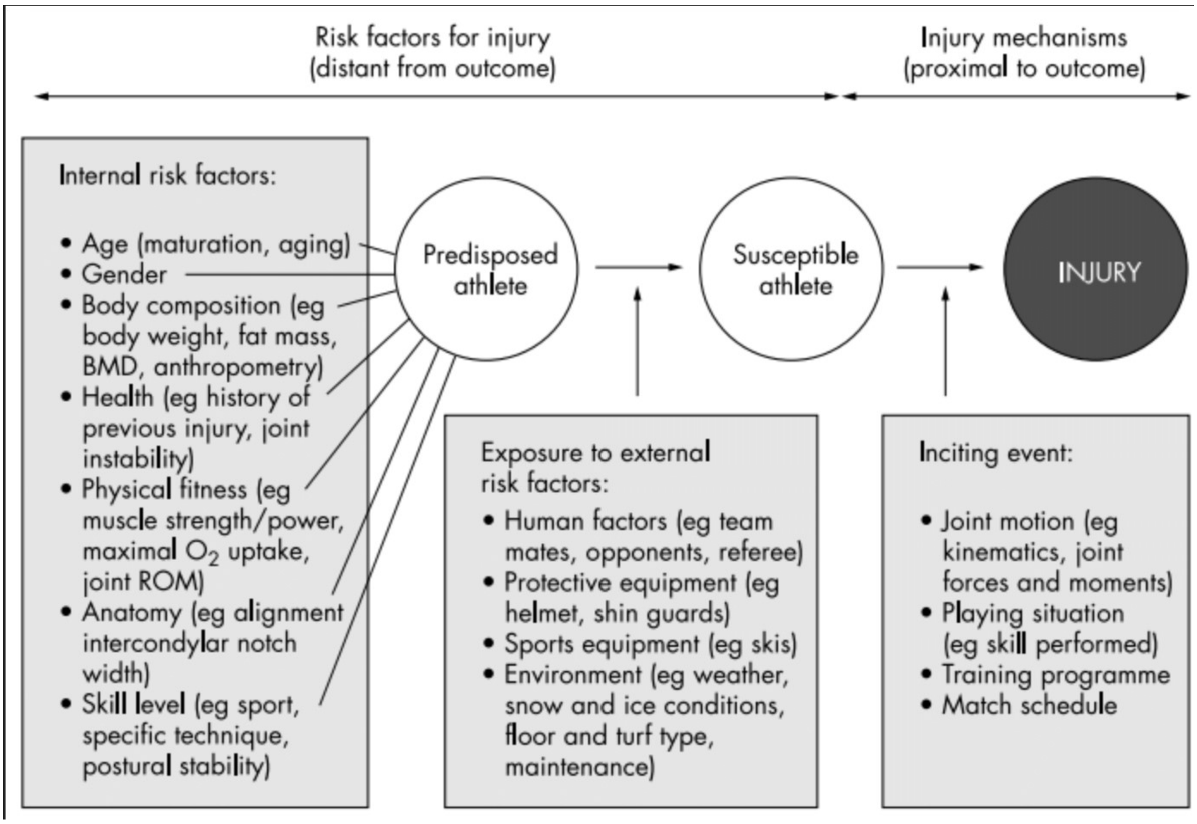

Figure 2.2: Meeuwisse et al. [87] Injury Causation Model

2.8 Playing position variations in injury risk

Studies investigating variations of risk predisposing players to injury among different playing positions in football showed conflicting results [89, 90, 92]. While goalkeepers possess the lowest injury rate, Dauty and Collon [90] found no significant difference in incidence rate across outfield playing positions among French elite football players. Others found an increase in injury rate for midfielders and forwards [89]. Previous data from the German Bundesliga indicated no statistical difference in the incidence rate of injuries among outfield players [44]. A potential limitation of previous studies is a relatively small sample size [44], including match injuries only [89] and the need to distinguish between central and lateral outfield playing positions. Due to the playing position's unique physical, technical and tactical characteristics, studies in which the precise positional role was not differentiated (i.e. central and wing positions) may overlook important information about differences predisposing players to specific injury risk. Therefore, study-1 aims to investigate risk differences between unique positional roles in football [50].

2.9 Seasonal dispositions of injuries

The distribution of injuries throughout a football season has been investigated in several studies [2, 24, 44, 89, 90]. Extreme fluctuations across the months of the season were identified. In some studies [44, 89], the difference between the highest (April) and lowest (September) injury count in the competitive phase of the season differ by 200%. Many reasons account for these considerable variations. Accumulated fatigue was outlined in the sports injury literature as a primary contributing factor accounting for these discrepancies [93]. In order to enhance knowledge of how match and training loads shape injury characteristics across the season, it is recommended to employ a period as opposed to a month-based analysis, as done in study 2. In line with the concept of periodization, professional football clubs organize a season into preparatory and competition periods. Each period has a unique profile regarding the work-recovery ratio, match-training ratio, and friendly/competition ratio, likely influencing injury characteristics directly across a season. Therefore, study two aims to describe the changes in risk players sustain across the different periods of a season [94]

2.10 Aims of the thesis

Male professional football clubs in 1BL receive tremendous exposure from mass media. Journalists are likely to query the technical team during a match or training session for current player health status if a player is assumed to be injured. For example, the reason a player is absent for match selection is likely to be raised during a match pre-conference. Furthermore, journalists routinely access club media (e.g. club web pages) and players' social media, which players use in seeking social support from their followers, especially during a long-lasting injury [105].

Thus, given the high rate and scarce information about injuries among Bundesliga football players, together with the absence of a prospective injury surveillance system in 1BL, the feasibility of implementing media-based injury data for research purposes may be promising, primarily due to a scarce insight available from this target group. However, the extent of validity and reliability needs to be established prior to the usage of data for sports injury research. If data is reliable, meaningful insight into injury characteristics and risk factors predisposing 1BL players may be obtained. The second part of the thesis aims to enhance insight into the mechanism predisposing football players to contact injuries.

Therefore, the aims of the PhD programme of work is the following:

Study (integrated in paper-1)

Pilot reliability study on the basic methodological assumption of the following papers, which use media data for monitoring injuries.

- To approximate the extent in which injuries documented in transfermarkt.de also appear in other media sources.
- To approximate the extent of injuries that were unreported in transfermarkt.de but indicate to appear in other media sources.
- To approximate the agreement between other media sources and transfermarkt.de indicating that player did not suffered an injury.
- To approximate the reliability of injury information (type, location and severity) in transfermarkt.de compared to other media sources.

Risk factor studies (paper 1-2)

- To describe the general injury pattern among 1BL players (injury type, locality, severity).
- To approximate injury risk differences between playing positions.
- To approximate injury risk differences between periods of a season.

Insight into mechanism of injury (paper-3)

- To outline a theoretical rationale for advancing understanding of how contact injuries may emerge in invasion team sports.

3 Methods

3.1 Study design

Study-1 and Study-2 aim to provide insight into external risk factors predisposing players to injury and describe the general injury pattern among 1BL football players. All empirical investigations in the current thesis use a retrospective observational study design. Study 3 is a review article outlaying a novel theoretical rationale for how contact injuries between opposing players in team sports may emerge in game situations.

3.2 Web Scraping the data

A web crawler was developed to extract raw data material supported in this thesis. Data corresponding to the player's general information (e.g. identification number, player name, club affiliation, age and height), as well as data related to the player's exposure in matches (i.e. number of minutes played per match) and player's injury history, was identified and extracted. The working scheme involves programming in R [95] to first retrieve relevant URLs and then extract information (often arranged in a tabular form) based on corresponding URLs.

The process of scraping data requires identifying relevant elements of interest and retrieving their identifiable selectors. The node that matches the selector of interest is then identified, extracted, and converted to a required format for further data processing purposes.

The following R packages were used: [96] (for managing general data wrangling tasks), rvest [97] (for parsing HTML files), stringr [98] (eases working with strings), and lubridate [99] (eases working with dates data).

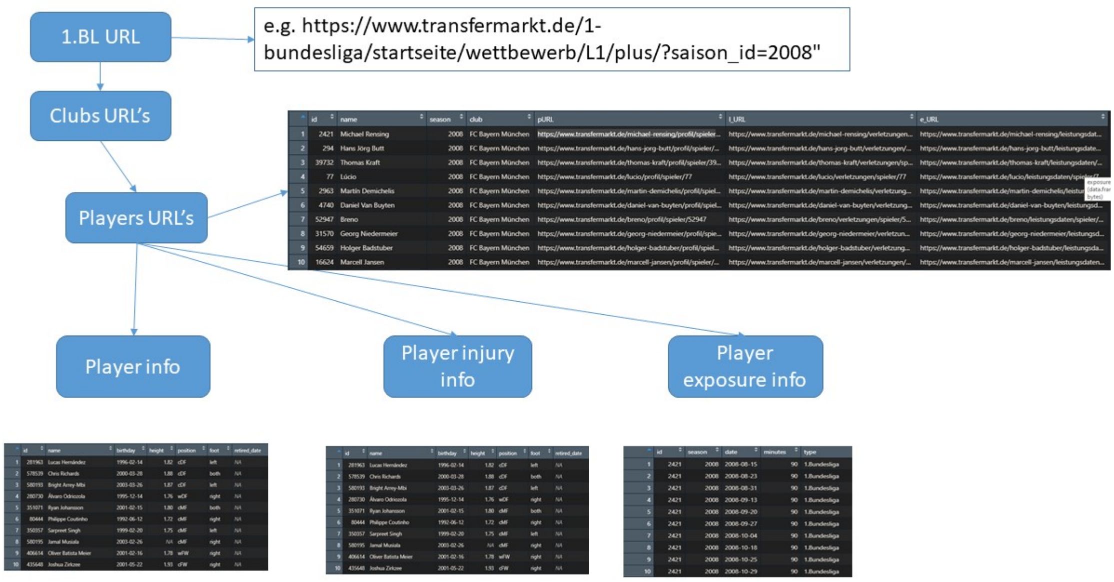

Figure 3.1: Web-scrapper flow chart

3.3 Data collection (for study 1-2)

All male players from one of the 18 teams in 1BL between 2008 and 2014 (contracted players) are included. Injury and exposure data and the following player information: name, age, team affiliation and playing position were extracted from the media register. Information on player injury is available in a tabulated form and comprises injury diagnosis (location and type), season injury occurred in, date injury is reported to start, date injury is reported to end, duration (in days) and number of matches a player missed due to an injury. Information on players' exposure to matches was extracted separately from the same media base source and contained the date and the number of minutes each player played in each season.

Information about injury diagnosis and player position was translated from German to English. This information was used to affirm the type and locality of the body part a player sustained. The categories for classifying the type and locality of injury were adopted in accordance with the guidelines of methodology in football injury-related research [31]. Information on player positional roles was aggregated into one of the following categories: Goalkeeper, Central Defender, Wing Defender, Central Midfielder, Wing Midfielder, and Striker.

3.4 Quality control

Before any empirical examination can be initiated, verifying the accuracy of the raw data extracted is necessary. Following the retrieval of the data, a rigorous examination was initiated. The objective was to scrutinize potential outliers, making sure as much as possible that deficiencies in data entry were verified and corrected. For example, an injury entry such as "arthroscopy" was verified to confirm if the entry indeed corresponded to an injury or an intervention. An intervention might occur if a player sustains an injury (intervention might be needed for such an injury, for example, knee ligament injury) nearby (less than 2 days). In this case, the arthroscopy injury was erased from the injury data. Information on player rehabilitation length (number of days missed) was aggregated with the player's previous injury (knee ligament injury). In other words, the player sustained only one injury, not two.

Because a player may sustain an injury during a match and hence indicated to be playing on the date of injury onset, entries indicating a player to be playing for up to 90 minutes on the day an injury occurred were included and were assigned as match injuries. Data was examined to identify cases in which players appear to be playing while rehabilitating from an ongoing injury. A data frame containing these observations was created for manual examination on a case-by-case basis. If exposure data indicated a player to be playing prior to the player's end date of injury, the end date of injury was not trustworthy and was therefore amended to the day before the player appeared to be engaged in match play. The injury database was also examined for cases in which the duration of rehabilitation a player sustained may overlap in multiple injury entries. Overlapping injury entries were assessed on a case-by-case basis in order to affirm if multiple injury entries belong to one single injury. This is especially likely because the player's end of rehabilitation is often a prior estimate. Journalists may overlook the existence of an injury entry already filed, adding a new one despite a report for the same injury already being registered. This shortcoming may lead to multiple injury entries belonging to one injury event. It is typical in such cases that several injury reports may share similar (or even identical) onset of (same) injury; however, the end date of an injury is likely to be registered later in each report. Therefore, injury data was crossed with exposure data to determine the latest time a player will likely be in rehabilitation from his onset of injury (typically the first injury report). Intermediate injury reports which appear to belong to the same injury event were removed from the injury inventory.

Statistical method	Study-1	Study-2
Descriptive statistics:		
Mean, median & inter-quartile range	✔	✔
Incidence rate with 95% CI	✔	✔
Analytic statistics:		
Kruskal-Wallis test	✔	
Mann-Whitney test	✔	
Wilcoxon signed-rank test	✔	
Regression analysis:		
Generalized Linear Model	✔	✔
Agreement analysis:		
Percent agreement	✔	
Cohen's Kappa	✔	

Table 3.1: Statistical methods integrated into studies

3.5 Statistical methods implemented

An overview of the statistical methods used is presented in Table 3.1.

Study-1 implemented a reliability and validity analysis on the primary data source (transfermarkt.de). Due to a lack of access to medical data, injury data was compared to two other media sources documenting injuries and players' absence from matches (Chatuvedi & Sommer GbR, Ligainsider and Cocotero Web International, Wettbasis). The data for comparison was retrieved in May 2016. The cross-validation procedure involved a 2-sided comparison. Injury data from the two reference sources described above were examined to affirm whether corresponding reports appear in transfermarkt.de. In addition, data from the reference sources were verified to confirm if recent injury reports appearing in transftermarkt.de are included. That is, checking to which extent injuries from the reference sources appear in transfermarkt.de and to which extent injury data from transfermarkt.de is included in these two reference sources selected for agreement analysis.

3.6 Analysis of injury rate and injury risk (for study 1-2)

In study 1, the incidence rate for match injuries was calculated as the total number of matches / 1,000 match hours. For overall (match and training injuries) and training-only injuries, the units of person-time at risk (i.e., the denominator) were 100 player seasons. In study-2, the units of person-time at risk for training injuries were 100 player weeks because a conscious decision was made to divide the season period into weeks. A key assumption in linear models (e.g. linear regression and analysis of variance) is that the residuals are normally distributed. When the response variable is skewed, a transformation such as a log transform can produce approximately normal residuals to meet this assumption. However, in sports injury research, the response variable is often the counted number of injuries, which is discrete, not continuous, and limited to non-negative values. In this case, such a transformation cannot produce normally distributed errors. There are two main problems when ordinary linear regression is applied to model these data. First, many players are likely to be safe, which leads to left-skewed data since many observations in the data set will have a value of 0. This inflated 0's in the data set prevents the transformation of a skewed distribution into a normal one. Second, it is pretty likely that the regression model will produce negative predicted values, which are not used in sports injury research. Due to these discrepancies, a Poisson regression model or one of its variants may be a suitable alternative. These models enable a skew discrete distribution and restrict the predicted values to non-negative numbers. The Poisson model is similar to an ordinary linear regression, with two exceptions. First, it assumes that the residuals follow a Poisson, not a normal distribution. Second, instead of modelling Y as a linear function of the regression coefficients, it models the natural log of the response variable ln(Y). However, the Poisson model assumes that the mean of the errors is equal to the variance, which is typically not the case in practical situations (the variance is likely greater than the mean). When the variance is larger than the mean (the standard deviation equals the square root of the mean), two extensions of the Poisson model work well [100]. In the quasi-Poisson model, an extra parameter is included, which estimates how much larger the variance is than the mean. This parameter estimate is then used to correct for the effects of the larger variance on the p-values. An alternative is a negative binomial model. The negative binomial distribution is a Poisson distribution in which the distribution's parameter is considered a random variable. The variation of this parameter can account for a variance of the data that is higher than the mean. Other families of models, such as zero-inflated models, have also been proposed to alleviate problems with overdispersed data [102]. Therefore, for study-1 and study-2, Poisson or Negative Binominal generalized linear regression models were implemented.

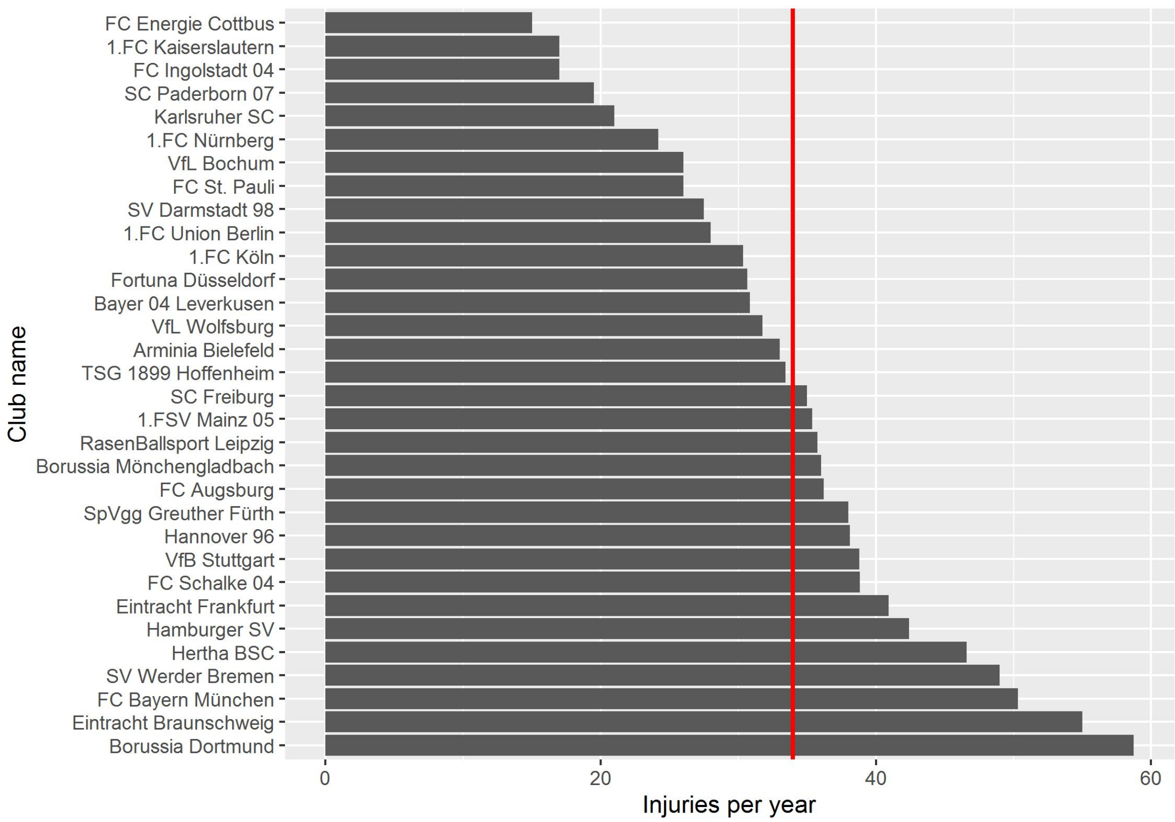

Figure 3.2: Injuries per season across clubs in the cohort

In Study-2 a mixed effect allowing the intercept to vary randomly between each player and each season was added to adjust for potential large variability between players/seasons. A random intercept was incorporated because some players and seasons may have a lower/higher probability of injury than others. Random intercepts allow insight into season-to-season and player-to-player variability in injury probability, often ignored using a fix-effect intercept. This method improve the ability to describe how fix effects related to outcome (probability of injury).

4 Results

4.1 Study-1

Leventer L, Eek F, Hofstetter S, and Lames M. “Injury patterns among elite football players: a media-based analysis over 6 seasons with emphasis on playing position”. In: *International Journal of Sports Medicine*. 37.11 (2016); pp. 898-908.

Injury Patterns among Elite Football Players: A Media-based Analysis over 6 Seasons with Emphasis on Playing Position

Authors L. Leventer[1], F. Eek[2], S. Hofstetter[3], M. Lames[1]

Affiliations
[1] Lehrstuhl für Trainingswissenschaft und Sportinformatik, Munchen, Technische Universität München, Germany
[2] Department of Health Sciences, Lunds Universitet, Lund, Sweden
[3] Department of Informatics, Technische Universität München, München, Germany

Key words
- epidemiology
- soccer
- male football

Abstract

The study objective was to describe the types, localizations and severity of injuries among first division Bundesliga football players, and to study the effect of playing position on match and training injury incidence and severity, based on information from the public media. Exposure and injuries data from 1 448 players over 6 consecutive seasons were collected from a media-based register. In total, 3 358 injuries were documented. The incidence rate for match and training injuries was 11.5 per 1 000 match-hours (95 % confidence interval [CI]: 10.9–12.2), and 61.4 per 100 player-seasons (95 % CI: 58.8–64.1), respectively. Strains (30.3 %) and sprains (16.7 %) were the major injury types, with the latter causing significantly longer lay-off times than the former. Significant differences between the playing positions were found regarding injury incidence and injury burden (lay-off time per incidence-rate), with wing-defenders sustaining significantly lower incidence-rates of groin injuries compared to forwards (rate ratio: 0.43, 95 % CI: 0.17–0.96). Wing-midfielders had the highest incidence-rate and injury burden from match injuries, whereas central-defenders sustained the highest incidence-rate and injury burden from training injuries. There were also significant differences in match availability due to an injury across the playing positions, with midfielders sustaining the highest unavailability rates from a match and training injury. Injury-risk and patterns seem to vary substantially between different playing positions. Identifying positional differences in injury-risk may be of major importance to medical practitioners when considering preventive measures.

accepted after revision
April 24, 2016

Bibliography
DOI http://dx.doi.org/10.1055/s-0042-108201
Published online: 2016
Int J Sports Med
© Georg Thieme Verlag KG Stuttgart · New York
ISSN 0172-4622

Correspondence
Louis Leventer
Technische Universität München
Lehrstuhl für Trainingswissenschaft und Sportinformatik
Uptown München-Campus D/Zimmer M210
80333 München
Germany
Tel.: +49/892/8924 504
Fax: +49/892/8924 497
leventer.louis@gmail.com

Introduction

Football (Association Football) at a professional level is a complex sport that involves a considerable injury-risk associated with a significant economic burden (e.g., a first team player being injured for one month costs the club around €500000) and reduced success on the pitch [15]. Empirical investigations indicate that, following a musculoskeletal injury, an athlete may be prone to enter a vicious cycle known as the continuum of disability [48]. The continuum of disability model postulates that tissue damage with long-lasting rehabilitation following an injury may result in reduced functional performance due to poor sensorimotor control and hence to an increased susceptibility to another injury in a cyclic manner. This reduction in sensorimotor control is postulated to emerge from an interplay between structural (e.g., damage to the mechanoreceptors of the affected ligament and associated tissues) and psychological factors (e.g., fear of re-injury). In football, evidence supporting this continuum may be found in examples such as the 22 % of hamstring injury recurrence within the first 2 months after an index injury was reported [37], the high prevalence of developing osteoarthritis after an anterior cruciate ligament (ACL) injury, chronic ankle instability following repeated sprains [45] and only one third of player's return to pre-injury level of competition following an ACL reconstruction after 12 months of rehabilitation [4]. Fear of re-injury [3], poor reaction time [42] and impaired self-esteem [47] are only a few setbacks players may face post-injury, even after a clearance for return to sport was granted by the team's medical personnel, and this may be associated with reduced functional performance. For example, a player's susceptibility to increased injury-risk may be a consequence of previous injury, evidenced on the pitch by errors in decision making [42]. Hence, an injury may result in both reduced performance and increased risk for new injuries, due to effects on physical and structural as well as psychological functions. Epidemiological evidence in partial support of these ideas indicates that the primary risk factor of an injury is a previous history of one [5, 34] and that major injuries were caused by minor injuries of the same type and locality [14].

The main goal of prevention is to avoid players entering the continuum of disability cycle to which an injury may predispose them. Van Mechelen's [44] model proposed that in order to provide preventive measures of sport injuries, an in-depth epidemiological overview in terms of injury incidence and severity is required. At the professional league level, epidemiological studies (mainly Scandinavian) show injury incidence rates of 16.1–28.2 match injuries and 2.0–11.8 training injuries per 1 000 h [7, 22, 23]. Research indicates that regional differences in injury incidence due to playing style, or intensity and climate plays an important role in shaping injury characteristics [30, 46]. For example, an audit showed a significantly higher overall injury incidence of traumatic and overuse injuries but lower rates of anterior cruciate ligament injury among professional teams from northern Europe with mild summers and cooler, temperate winters compared to more southern teams with a Mediterranean climate [46]. Therefore, in order to implement preventive measures for a specific target population, it may be critical to provide evidence about that particular population injury pattern as a first step.

The German Premier League (Bundesliga) is considered one of the best leagues in terms of performance in professional football worldwide. For example, for over 2 decades, it is the league with the highest number of goals per game among top leagues in Europe [38]. Still, very limited attention seems to be directed towards the evaluation of injury-risk in German professional football. Up to date, to the best of our knowledge, only 2 scientific studies exploring injury-risk in the Bundesliga, one by aus der Fünten et al. [6] and another by Faude et al. [19], have so far been published. The study by aus der Fünten et al. [6] examined injury-risk by analyzing the effect of a shortened winter break in relation to injury incidence. The results showed an injury incidence of between 26.5 and 31.5 match injuries and between 2.7 and 4.0 training injuries per 1 000 h. However, despite using a prospective design, their sample comprised teams playing in both the 1st and 2nd divisions, and their analysis was limited to just 7 teams while only collecting data during half a season. Faude et al. [19] studied injury characteristic during one full season solely among 1st division Bundesliga (1BL) players by collecting injury information from mass media, indicating an incidence rate in the upper range of values reported in professional leagues: 37.5 match injuries per 1 000 h. Most injuries were classified as strains, and forwards were shown to sustain the highest injury-risk, followed by defenders and midfielders. The differences in injury-risk across playing positions has been examined in several studies [9, 10, 40]. With the exception of Carling et al. [9], to the best of our knowledge, only 4 typical playing positions (goalkeeper, defender, midfielder and forward) were differentiated. An analysis of elite performance suggests that different positional roles require unique technical, physiological and tactical demands from the players. For instance, central-defenders are more frequently engaged in aerial duels than wing-defenders, and wing-midfielders cover significantly greater distances while sprinting than central-midfielders [12]. These unique technical and physiological demands might predispose players to greater risk for certain types of injuries, such as increased risk for concussions among central-defenders and strains among wing-midfielders due to eccentric overload of the musculo-tendon junction that have been found to emerge when sprinting [36]. Therefore, previous studies in which the precise positional roles were not considered may have overlooked important information about certain playing positions being predisposed to specific injury patterns.

Taken together, the need to study injury specific patterns among Bundesliga players, preferably over multiple seasons [31], alongside with the high values of injury incidence found, and the lack of a prospective injury surveillance system, call for additional epidemiological studies within this area based on public media. A study based on media information may provide the ground for future prospective studies of injury incidence, and potential risk factors for injury. Therefore, the aim of this study is 2-fold. The first is to describe injury types, severity and location among 1BL football players by means of a media-based register. The second is to investigate injury characteristics among the different positional roles of this target population.

Materials and Methods

Study design and population

The study was designed as a retrospective observational cohort design. The study sample includes all (1 448) male football players assigned to one of the 18 teams playing in the 1BL from July 2008 until June 2014. Players on trial or youth players without a professional contract were not included. Mean player's age was 27.7 years (SD = 5.1; range: 18–47) and height was 1.83 meters (SD = 0.05; range: 1.67–2.01).

Data collection

All materials used in this study were retrieved from Transfer-Markt.de, an online open-source sports database (Transfermarkt GmbH & Co. KG, Transfermarkt. In Internet: www.transfermarkt.de (data retrieved 04–11/12/2014)). This data source was selected because it provides information of injury per player in a longitudinal manner. In serving their audience (mainly scouts) the database aims to provide insight into player transfers. In professional soccer, player injury history thus is of high importance during negotiations when considering the market value of incoming players to squads.

Data from the 2008/9 season through the 2013/14 season (6 full consecutive seasons), including pre-season was analyzed. Information about every player in the cohort was obtained regarding matches played during each season including number of minutes played for each match and injury history. Player's injury history is available in a tabulated form as part of each player's technical details in the database and includes reports of start/end date of injury, injury type and/or localization, and number of days and matches missed per each injury. Also general information such as age, playing position and number of seasons assigned to a 1BL team was collected from the database.

Data quality control

Since the results are based on secondary data sources rather than direct medical reports, certain measures were taken in order to check the validity and reliability of the data. Due to lack of direct access to medical reports – the gold standard – other secondary data sources were used as a reference for assessing the validity and reliability of transfermarkt.de. Following a scrutinized search, injury data from 2 independent media sources –

Chaturvedi & Sommer GbR, Ligainsider. In Internet: http://www.ligainsider.de/bundesliga/verletzte-und-gesperrte-spieler/ (Data retrieved 09-20/02/2016) and Cocotero Web International Ltd, Wettbasis. In internet: http://www.wettbasis.com/deutschland-bundesliga-verletzte-und-gesperrte-spieler.php (Data retrieved 09–20/02/2016). These sources were selected due to their aim, that is, to provide information about the most current status of each team for the nearest playing fixture. Specifically, in preparing their audience (especially betters) for the upcoming match, information from these sources about player unavailability to matches due to a sanction or injury is of utmost value, and therefore, was assumed to be trustful.

The cross-validation procedures involved a 2-sided comparison. Data from the reference sources was examined in order to affirm whether corresponding reports appear in transfermarkt.de. In addition, entries of player injury histories were cross-references in order to affirm whether both sources (transfermarkt.de and reference sources) agree that no injury was documented.

Since transfermarkt.de is a database, and hence, its primary aim is to provide a resource for player performance and injury history, as opposed to these 2 sources which, due to their different objectives, aim to provide a picture of the most current status of the teams, we accounted for possibilities that very recent injuries might be reported in delay in transfermarkt.de. Therefore, in order to overcome this bias, we decided to include only injuries reported over a 2-week time period prior to the actual moment of data acquisition. To estimate reliability, a one-sided cross-validation was examined. Information about injury type/localization was verified in order to determine the percentage of inter-observed agreement.

A manual check of the data was implemented when required as part of the quality control phase by 2 physiotherapists (LL and FE) in cases where reports were suspected of being inconclusive. Finally, absence days and missed matches were cross-referenced against exposure registration for accuracy in selected cases.

Injury definition

We adopted a time-loss injury definition according to the consensus statement for injury definitions in studies of football injuries [20]. Therefore, an injury was defined by the following: if the player was unable to take full part in football activity or match play at least one day beyond the day of injury. The player was considered injured until his reported end date of injury. An injury was considered a match injury if reported on the same day or the following day of a match in which the player was playing. A training injury was defined as an injury reported on any other day than a match injury. Injury severity was categorized according to the definition suggested by the consensus guidelines in studies of football injuries as the following: minimal (1–3 days), mild (4–7 days), moderate (8–28 days) and severe (> 28 days).

Exposure time

Exposure time was calculated separately for match and training injuries. For match injuries, player exposure was based on player's actual time reported (in minutes) to be playing during each official match in the season. Playing time during friendly and unofficial matches was not taken into account. Due to the lack of information regarding each individual training time per training session, person-time was measured as a player-season for training injuries and also for aggregated measures of overall injury incidence [33].

Statistics

The incidence of match injuries was calculated using the formula: (number of injuries × 1 000 match-hours)/(minutes of exposure/60) and expressed as the number of injuries per 1 000 match-hours. Training injury incidence, as well as the aggregated measures of overall injury incidence were computed as per 100 player-seasons. Injury burden was calculated as the number of injury days lost per 1 000 match-hours for match injuries and 100 player-seasons for training injuries (injury incidence × mean absence per injury), thus accounting for both injury incidence and severity [25]. Player's match unavailability was calculated per player as '∑ of player match opportunities (= number of season in the cohort multiplying 34 matches of the Bundesliga per season) – ∑ of player match absences due to an injury' and expressed as the average player's match availability in percentage [25]. Injury burden (IB) and match unavailability (MuA) 95 % confidence intervals (CI) were calculated using the formula: IB or MuA ± 1.96 × (IB or MuA/√ ∑ number of days or matches missed). Injury incidence with 95 % CI was calculated assuming a Poisson distribution.

The Incidence Rate Ratio (IRRs) and the test for a significant trend in injury incidence as well as in injury burden rate ratio (IBRR) and match unavailability rate ratios (MuARR) across the different playing positions were calculated assuming a Poisson or negative binominal distribution using a Poisson or negative binominal regression model when appropriate [33,40]. Forward was the playing position selected as a reference category for the distribution of overall injury incidence, injury burden and match unavailability rates across the different playing positions since past studies [9,19] indicated the forward position as sustaining the highest overall injury-risk. For the profiles of selected injuries incidence rate across the different playing positions, the playing position with the highest injury incidence was assigned as a reference category.

Since number of days per matches absent due to an injury showed a highly skewed distribution with some extreme outliers, a Mann-Whitney test was used to compare days and matches missed following match and training injuries. A Kruskal-Wallis test with pairwise post-hoc comparison was used to compare days and matches missed among injury type (joint/ligament, muscle and contusions) and location (body part of the lower-extremity). Inter-observer agreement rate was analyzed with Cohen's Kappa, in order to determine the rate of validity of the data (i.e., consistency in the injury database) [1]. Alpha was deemed to be significant if p-value was < 0.05. Analyses were performed using the Epitools package (v. 0.5-7) [2] in R (v. 3.1.2) [43] and SPSS (v. 22.0).

Results

▼

Cross-validation and reliability

In total 330 cases were examined. Of them 159 injuries were verified between the reference sources and the injury data in transfermarkt.de. Results indicate an inter-observer agreement of 91.1 % (agreement 1: between reference sources to transfermarkt.de, and agreement 2: between transfermarkt.de to reference: 89 % and 95 %, respectively). These values correspond to a Cohen's kappa = 0.82 for the cross-validation. Inter-observer agreement in the reliability of injury type/localization was 89 %.

Exposure rate, injury incidence and overall severity

A total of 110 217 match-hours and 3 401 player-seasons were registered during the overall 6 seasons. A total of 3 358 injuries were recorded comprising 1 270 (37.8 %) match injuries and 2 088 (62.2 %) training injuries, corresponding to a mean of 0.4 injuries per player per season or 31.1 injuries per team per season.

The overall injury incidence during the study period was 98.7 (95 % CI: 95.4–102.1) per 100 player-seasons, and the injury burden was 1 776.6 (95 % CI: 1767.0–1786.1) days lost per 100 player-seasons. The incidence of match injuries was 11.5 (95 % CI: 10.9–12.2) per 1 000 match-hours, and injury burden was 172.5 (95 % CI: 170.9–174.1) days lost per 1 000 match-hours. The incidence rate of training injuries was 61.4 (95 % CI: 58.8–64.1) per 100 player-seasons, and injury burden was 1166.6 (95 % CI: 1158.8–1174.4) days per 100 player-seasons. Total mean player unavailability to matches was 16.9 % (115,634 match opportunities and 19 526 matches missed due to an injury). The median number of day's absence per injury was 18 days, interquartile range (IQR) 8–43 and 3 matches (IQR: 1–6). There was a significant difference in the distribution of days absent from matches (median: 19 days; IQR: 8–47) and training injuries (median: 18 days; IQR: 7–43) ($p = 0.002$), with days absent following training injuries showing a slightly higher mean rank. Despite similar medians (3 matches, for both match and training injuries), a Mann-Whitney test indicates a significant difference in the distribution of matches absence between match and training injuries ($p = 0.02$), with match injuries showing a slightly higher mean rank of matches absence, compared to training injuries. As indicated in **Table 1**, the incidence rate of moderate injuries were the highest among match injuries (IR: 4.8 [95 % CI: 4.4–5.2]/1 000 match-hours), and among training injuries (IR: 23.5 [95 % CI: 21.9–25.2]/100 player-seasons).

Injury type and localization

As indicated in **Table 1**, the most common injury type was muscle injury (30.3 % of all injuries), followed by joint/ligament injury (16.7 %). The third most common injury type among match injuries was contusion (8.5 %), and among training injuries, tendon injury (6.1 %). The Kruskal-Wallis test indicated a significant difference ($p < 0.001$) in the days of recovery following muscle, ligament/joint and contusion. Pair-wise comparison indicated significantly ($p < 0.001$) longer time of recovery from ligament/joint injury compared to muscle and for muscle and ligaments compared to an injury from a contusion. There was also a significant difference in absence following different locations of injuries. Pair-wise comparison indicated that the number of days of absence following a knee injury was significantly ($p < 0.001$) longer compared to all other locations on the lower-extremities, while recovery from a thigh injury was significantly shorter compared to all other locations of the lower-extremities. Significantly longer recovery time was observed following foot/toe injury compared to hip/groin injury ($p = 0.002$; **Table 1**).

Playing position

Table 2 shows the injury incidence across the different playing positions. The differences between the groups in relation to injury incidence were statistically significant for both match and training injuries ($p < 0.01$). Of match injuries, wing-midfielders sustained the highest injury incidence of 12.9 (95 % CI: 11.1–14.9)/1 000 match-hours. Of training injuries, central-defenders and wing-midfielders sustained the highest injury rate (central-defenders: IR = 65.5 [95 % CI: 59.3–72.1]/100 player-seasons; wing-midfielders: IR = 64.2 [95 % CI: 57.1–71.9]/100 player-seasons).

Injury burden across the playing positions

Table 3 shows the injury burden across the different playing positions. The difference between the lay-off time per incidence rate across the playing position was statistically significant ($p < 0.001$). The burden of injury among central-midfielders relative to forwards was significantly higher in matches IBRR = 1.32 (95 % CI: 1.21–1.56), as well as in training IBRR = 1.21 (95 % CI: 1.03–1.41). Of match injuries, wing-midfielders sustained the longest overall lay-off time, significantly longer compared to forwards IBRR = 1.42 (95 % CI: 1.26–1.79). However, despite 20 % higher rates compared to forwards, the relative rate of burden from training injuries was not significantly different IBRR = 1.20 (95 % CI: 0.99–1.44). The burden of injury among central-defenders was significantly higher relative to forwards in both matches (IBRR = 1.21 [95 % CI: 1.02–1.45]) and training (IBRR = 1.17 [95 % CI: 1.01–1.40]).

Match availability across the playing positions

Table 4 shows the distribution of match unavailability and match unavailability rates across the different playing positions. The highest percentage of match unavailability among the different field players was among wing-midfielders (18.8 %), followed by central-defenders (18.6 %). The difference in the rate of absence from matches across the playing positions was statistically significant for both match and training injuries ($p < 0.001$). Midfielders had significantly higher match unavailability rates relative to forwards from match injuries (wing-midfielders: MuARR = 1.45 [95 % CI: 1.18–1.78]; central-midfielders: MuARR = 1.48 [95 % CI: 1.23–1.77]) and from training injuries (wing-midfielders: MuARR = 1.26 [95 % CI: 1.04–1.54]; central-midfielders: MuARR = 1.21 [95 % CI: 1.02–1.43]). Following match injuries, central-defenders had significantly higher match unavailability rates relative to forwards: MuARR = 1.37 (95 % CI: 1.13–1.66).

Playing position injury profiles

Fig. 1 illustrates the injury profiles of each playing position in reference to the incidence of injury and injury burden in adductor, hamstring and groin strains, ankle sprain and knee medial collateral ligament lesions. As indicated in **Table 5**, the difference between the injury rates across the playing positions was statistically significant among hamstring and groin strains ($p < 0.05$). Injury incidence of groin strain was significantly lower among wing-defenders (IRR: 0.43 [95 %CI: 0.17–0.96]) and goalkeepers (IRR: 0.04 [95 % CI: 0.03–0.44]) compared to forwards (reference category). The rate of hamstring strain was significantly lower (84 %) in goalkeepers compared to central-midfielders (IRR: 0.16 [95 % CI: 0.03–0.36]), while the rate of sustaining an adductor strain was significantly lower (71 %) in goalkeepers compared to central-defenders (IRR: 0.29 [95 % CI: 0.11–0.56]). Ankle sprains and MCL-injuries were, despite relatively low incidences, the injuries causing the highest burden on players, leading to 280 (ankle sprain) and 84.6 (MCL) days of absence per 100 player season, respectively. However, the burden differed substantially between playing positions. Few days were lost due to an ankle sprain among forwards compared to other positions, while more days were lost among midfielders (central and wing). For all injury types, the burden was much lower for goalkeepers compared with all field playing positions. Groin strain had a higher injury burden for forwards, compared to all other playing positions. From player position perspective, defenders (central-defenders: 121.6 lay-off days/100 player-seasons and

Table 1 Injury pattern by type localization and severity.

	Total Injuries				Match Injuries				Training Injuries			
Injury Type	**N Injuries (%)**	**Days Missed M (IQR)**	**Matches Missed M (IQR)**	**IR per 100 PS (95% CI)**	**N Injuries (%)**	**Days Missed M (IQR)**	**Matches Missed M (IQR)**	**IR per 1000 MH (95%CI)**	**N Injuries (%)**	**Days Missed M (IQR)**	**Matches Missed M (IQR)**	**IR per 100 PS (95%CI)**
Fracture S	23 (0.7)	58 (42–71.5)	8 (5.5–11)	0.67 (0.43–1.01)	–	–	–	–	23 (1.0)	58 (42–71.5)	8 (5.5–11)	0.63 (0.40–0.94)
Fracture T	180 (5.4)	30 (13.5–68.5)	4 (2–8)	5.29 (4.54–6.12)	90 (6.8)	28.5 (11–60)	4 (2–8)	0.82 (0.65–1.03)	90 (4.7)	37.5 (19–78)	4.5 (2–8)	2.64 (2.12–3.25)
Joint/Liga	561 (16.7)	39 (15–75)	5 (2–12)	16.49 (15.16–17.92)	**267 (20.7)**	**34 (13–64)**	5 (2–11)	2.42 (2.14–2.73)	**294 (14.4)**	**31.5 (13–65)**	4 (2–10)	8.64 (7.68–9.69)
Menisc/C	113 (3.4)	82 (41–144)	10 (5–18)	3.32 (2.73–3.99)	25 (2.0)	68 (42–146)	8 (5–20)	0.23 (0.15–0.33)	88 (4.0)	82.5 (42.5–146)	10.5 (5–17)	2.59 (2.01–3.19)
Contusions	216 (6.4)	7 (4–13)	1 (1–3)	6.35 (5.55–7.25)	114 (8.5)	7 (4–13)	1 (1–3.5)	1.03 (0.85–1.27)	102 (5.3)	7 (4–15)	2 (1–3)	3.00 (2.44–3.64)
Muscle	**1016 (30.3)**	**15 (8–29)**	**2.5 (1–5)**	**29.87 (28.06–31.77)**	391 (30.8)	14 (9–27.5)	3 (2–5)	**3.54 (3.20–3.91)**	625 (29.9)	15 (7–30)	2 (1–4)	**18.87 (16.96–19.87)**
Tendon	159 (4.7)	31 (12.5–72.5)	5 (2–9)	4.67 (3.97–5.46)	36 (3.0)	27.5 (11–75.25)	4 (2–10)	0.34 (0.25–0.47)	123 (6.1)	31 (12.5–71.5)	5 (1–9.5)	3.61 (3.00–4.31)
CNS/PNS	36 (1.1)	7 (4.5–13)	2 (1–5)	1.05 (0.74–1.46)	26 (2.3)	7 (5–13)	2 (1–3)	0.23 (0.15–0.34)	10 (0.5)	5.5 (4–7.75)	2 (1.25–2)	0.29 (0.24–0.36)
Unknown	1054 (31.4)	13 (6–41)	2 (1–6)	30.99 (29.15–32.92)	321 (25.9)	10 (5–27)	2 (1–4)	2.9 (2.60–3.20)	733 (34.0)	14 (7–42)	2 (1–6)	21.64 (20.15–23.20)
Total:	3358 (100)	18(8-43)	3 (1–6)	98.73 (95.42–102.13)	1270 (100)	19 (8–47)	3 (1–7)	11.52 (10.89–12.17)	2088 (100)	18 (7–43)	3 (1–6)	61.39 (58.80–64.08)
Common Injuries:												
Knee Cruciate L	77	191 (154–222)	23 (16–37)	2.26 (1.79–2.83)	40	198.5 (169–229)	25 (21–37)	0.36 (0.25–0.49)	37	175 (120–219)	19 (14–34)	1.08 (0.75–1.49)
Knee CL	105	42 (21–59)	5 (2–9)	3.09 (2.52–3.74)	48	41.5 (20–56.5)	5 (2–8)	0.43 (0.32–0.57)	57	42 (23–64)	5 (2–9)	1.67 (1.12–2.17)
Ha/Add	380	10 (6–22)	2 (1–4)	11.17 (10.08–12.35)	144	10 (6–10)	2 (1–2)	1.30 (1.10–1.53)	236	11 (6–22)	2 (1–3.25)	6.13 (5.87–6.40)
Ankle Sprain	296	29 (14–45)	4 (2–7)	8.70 (7.74–9.75)	119	28.5 (12–54)	4 (2–8)	0.22 (0.14–0.33)	177	29 (13–61)	4 (2–10)	5.20 (4.46–6.03)
Achilles Tear	69	29 (9.5–63)	4.5 (2–9)	2.21 (1.58–2.57)	16	31 (13–72.2)	5 (2–9.25)	0.13 (0.08–0.21)	53	28 (8–56)	4 (2–7)	1.44 (1.08–1.89)
Injury Location												
Head/Neck	103 (3.1)	10 (6–17)	2 (1–3)	3.02 (2.47–3.67)	68 (5.4)	10 (5–16)	2 (1–4)	0.61 (0.48–0.78)	35 (1.7)	10 (6.5–19.5)	2 (1–2)	1.03 (0.72–1.43)
Upper–limbs	165 (4.9)	21 (11–42)	4 (2–6)	4.85 (4.14–5.65)	77 (6.1)	23 (11–42.5)	4 (2–7)	0.70 (0.55–0.87)	88 (3.6)	19 (11–41)	3 (2–6)	2.59 (2.01–3.19)
Trunk	188 (5.6)	13 (6–33)	2 (1–5)	5.52 (4.76–6.37)	53 (4.2)	13 (7–28)	2 (1–4)	0.48 (0.36–0.63)	135 (2.1)	13 (6–33)	2 (1–5)	3.96 (3.32–4.69)
Buttock	175 (5.2)	12 (5–40)	2 (1–4)	5.14 (4.44–5.96)	45 (3.5)	12 (6–28.5)	2 (1–4)	0.41 (0.30–0.55)	130 (5.9)	12.5 (5.5–42)	2 (1–5)	3.82 (3.19–4.53)
Hip/Groin	161 (4.8)	20 (7–55)	3 (1–7)	4.73 (4.03–5.52)	43 (3.4)	13 (7–56)	4 (2–7.5)	0.39 (0.28–0.53)	118 (10.1)	14 (7–38.5)	2 (2–2)	6.47 (5.64–7.38)
Thigh	410 (12.2)	10 (5–18)	2 (1–4)	12.05 (10.91–13.28)	153 (12.0)	10 (5–19)	2 (1–4)	1.39 (1.17–1.62)	257 (6.0)	10 (6–20)	2 (1–3)	7.56 (6.66–8.53)
Knee	**548 (16.3)**	**43 (13–95.5)**	**5.5 (2–14)**	**16.11 (14.79–17.52)**	**185 (14.6)**	**43 (13–100)**	6 (2–18)	**1.68 (1.44–1.93)**	**363 (17.2)**	**42 (13–88.5)**	5 (2–12.5)	**10.38 (9.32–11.52)**
Lower–leg/A	183 (5.4)	14 (2–46.5)	3 (0–7)	5.38 (4.62–6.22)	56 (4.4)	10.5 (6.75–52)	3 (1–7)	0.51 (0.38–0.66)	127 (6.0)	15 (7–43)	2 (1–7)	3.73 (3.11–4.44)
Ankle	323 (9.6)	18 (1–43)	3 (0–6)	9.49 (8.48–10.59)	146 (11.5)	21 (9–40.5)	4 (2–6.5)	1.32 (1.18–1.55)	177 (6.0)	18 (6–46)	3 (1–6)	5.20 (4.46–6.03)
Foot/Toe	178 (5.3)	26 (1–75)	4 (1–9)	5.23 (4.49–6.06)	63 (5.0)	21 (7–53)	4 (1–10)	0.57 (0.44–0.73)	115 (5.3)	29 (9–81.5)	4 (1–9)	3.38 (2.80–4.05)
Unknown	924 (27.5)	15 (7–31.25)	3 (1–5)	27.17 (25.44–28.97)	381 (30.0)	14 (8–29)	3 (1–5)	3.45 (3.11–3.82)	548 (26.2)	17 (7–34)	2 (1–1)	16.11 (14.79–17.52)
Injury Severity												
Mini (1–3 d)	196 (5.8)	3 (2–3)	1 (0–1)	5.76 (4.98–6.29)	78 (6.2)	3 (2–3)	1 (1–1)	0.71 (0.56–0.89)	118 (5.6)	3 (2–3)	1 (0–1)	34.69 (28.70–41.50)
Mild (4–7 d)	621 (18.5)	5 (4–7)	1 (1–2)	18.26 (16.85–19.75)	243 (19.1)	5 (4–6)	1 (1–2)	2.20 (1.93–2.50)	378 (18.1)	6 (5–7)	1 (1–1)	11.11 (10.01–12.29)
Mod (8–28 d)	1327 (39.5)	14 (11–20.5)	2 (2–4)	39.02 (36.94–41.17)	526 (41.4)	14 (10–20)	3 (2–4)	4.77 (4.37–5.20)	801 (38.4)	14 (11–20)	2 (1–3)	23.55 (21.95–25.24)
Sev (>28 d)	1214 (36.2)	60 (40–103)	8 (5–15)	35.69 (33.71–37.76)	423 (33.3)	55 (39–101)	9 (6–16)	3.83 (3.48–4.22)	791 (37.9)	63 (41–108)	8 (5–15)	23.26 (21.66–24.94)

M = median; IQR = Inter-quartile range; IR = Incidence rate; CI = confidence interval; MH = match-hours; PS = Player-season; CNS/PNS = central/peripheral nervous system; S = stress; T = trauma; Liga = ligament; Menisc/C = Meniscus/cartilage; L = ligament; CL = collateral ligament; Ha/add = hamstrig/Adductor; A = Achilles; d = days Min = minimal' Mod = moderate; Sev = Severe

Table 2 Injury incidence for the different playing positions.

	Match Injuries					Training Injuries				
	Injuries (%)	Exposure (MH)	IR (95% CI)	IRR (95% CI)	p-value	Injuries (%)	Exposure (PS)	IR (95% CI)	IRR (95% CI)	p-value
Goalkeepers	75 (5.9)	10992	6.82 (5.36–8.55)	0.63 (0.49–0.82)	<0.001	163 (7.8)	386	42.22 (35.99–49.23)	0.73 (0.61–0.88)	0.001
Central Defenders	278 (21.9)	22275	12.48 (11.05–14.04)	1.16 (0.97–1.40)	0.099	410 (19.7)	626	65.49 (59.30–72.15)	1.08 (0.94–1.25)	0.283
Wing Defenders	174 (13.7)	16982	10.24 (8.78–11.88)	0.97 (0.79–1.19)	0.756	289 (13.8)	493	58.62 (52.05–65.78)	0.98 (0.83–1.14)	0.763
Central Midfielders	358 (28.2)	29429	12.16 (10.93–13.49)	1.09 (0.92–1.30)	0.309	579 (27.7)	896	64.62 (59.46–70.10)	1.07 (0.94–1.22)	0.326
Wing Midfielders	183 (14.4)	14185	12.90 (11.10–14.91)	1.10 (0.90–1.34)	0.356	298 (14.3)	464	64.22 (57.13–71.94)	1.03 (0.88–1.20)	0.723
Forwards	202 (15.9)	16354	12.35 (10.70–14.18)	1.00 (reference)		348 (16.7)	536	64.92 (58.28–72.11)	1.00 (reference)	

IR = Incidence rate; MH = Match hours; PS = Player-season; CI = Confidence Interval; IRR = Incidence Rate Ratio

Table 3 Distribution of injury burden across the playing positions.

	Match Injuries					Training Injuries				
	DM M (IQR)	Ø D/Injury	IB (95%CI)	IBRR (95% CI)	p-value	DM M (IQR)	Ø Days/Injury	IB (95%CI)	IBRR (95% CI)	p-value
Goalkeepers	24 (7.5–44)	38.7	264.2 (254.6–273.9)	0.61 (0.51–1.36)	0.40	23.0 (9.0–52.5)	42.1	1778.4 (1736.3–1820.5)	0.86 (0.71–1.05)	0.131
Central Defenders	15.5 (8.0–41.75)	34.7	433.3 (424.6–441.9)	1.21 (1.02–1.45)	0.04	21.0 (8.0–45.5)	40.9	2743.1 (2702.1–2784.1)	1.17 (1.01–1.40)	0.043
Wing Defenders	16.0 (7.0–37.0)	32.7	335.1 (326.4–343.8)	0.97 (0.80–1.18)	0.93	19.0 (8.0–56.0)	41.6	2575.2 (2530.4–2620.0)	1.19 (1.10–1.50)	0.053
Central Midfielders	15.0 (6.0–36.0)	38.8	472.1 (464.3–480.0)	1.32 (1.21–1.56)	0.01	19.0 (8.0–50.5)	41.4	2744.6 (2710.3–2778.9)	1.21 (1.03–1.41)	0.022
Wing Midfielders	15.0 (8.5–40.5)	40.8	526.5 (514.5–538.4)	1.42 (1.26–1.79)	0.000	15.0 (8.0–42.0)	40.4	2719.4 (2672.0–2766.9)	1.20 (0.99–1.44)	0.056
Forwards	15.0 (8.0–33.0)	34.7	428.2 (418.1–438.2)	1.00 (reference)		17.0 (7.0–41.0)	36.1	2344.7 (2303.8–2385.7)	1.00 (reference)	

IB = Incidence rate; MH = Match hours; PS = Player-season; CI = Confidence Interval; IBRR = Incidence Rate Ratio; M = median; IQR = inter-quartile range; DM = days missed; D = days

wing-defenders: 102.1 lay-off days/100 player-seasons) and central-midfielders (94.3 lay-off days/100 player-seasons) suffered the longest lay-off time following an MCL injury. Among forwards, groin strain resulted in the highest injury burden (110 lay-off days/100 player-seasons). Ankle sprain led to the longest lay-off times among central-midfielders (110.4 lay-off days/100 player-seasons) and wing-midfielders (100.6 lay-off days/100 player-seasons).

Discussion

The aim of the present study was to describe the type, location and severity of injuries among 1BL football players, and to investigate injury patterns among different player positions, using media-based register data.

An analysis of injuries based on media sources have previously been carried out in the English Premier League [29], and more recently in the 1BL [19]. This method provides an estimation of the injury patterns and, in the absence of a prospective direct medical surveillance system, which is undoubtedly the gold standard, it may serve as an alternative when administered in leagues with extensive media coverage. It is hypothesized that high media coverage, as reflected in events to which journalists have frequent access such as pre- and post-match press conferences and daily attendance of training sessions among others may lead to more complete and accurate reports of injuries. Journalist reports from such events are being registered regularly on transfermarkt.de in order to provide the public with insight into player performance, based on which stakeholders may negotiate prospective player transfers. Specifically, player injury history plays a major role in deciding potential player market value. For example, players with extensive injury history might be less attractive for loans to other clubs, a factor that may downgrade the player's individual market value.

From a methodological point of view, a major limitation of an analyses based on media reports is a lack of information regarding the extent of data quality, specifically, its reliability and validity. Thus, several measures addressing this discrepancy were implemented as part of the design of the study and the quality control procedures. At first, due to high media coverage compared to lower leagues, a deliberate decision was taken to focus solely on the Bundesliga first division. Following this, in an attempt to verify the extent and precision to which injuries were recorded, the validity and reliability of the data were assessed by cross-referencing injury reports (obtained from selected media sources) with our injury data. Results indicate an almost perfect agreement in cross-validation and very high agreement regarding the reliability of the information. Care should be taken, however, since the cross validation with another secondary source of information as reference does not equate to a true validation referring to gold standard in consisting of primary and directly observed and collected injury reports. However, also direct injury reports could potentially be subjected to bias due to lack of compliance with protocols, etc. A recent methodological study among Norwegian professional footballers showed that medical staff reporting failed to capture about 20% of all time loss injuries [8]. Moreover, the sources used as a reference in the cross-validation procedure aim to prepare their target groups – mainly betters – for the next match. Therefore, documenting injuries to describe the most current status of the teams is of major impor-

Table 4 Distribution of match availability across the different playing positions.

	Total MuA (%)	Match Injuries: Matches Missed M (IQR)	∑ Match Oppor-tunities	∑ Matches Missed	MuA (%)	Ø Match/ Injury	Match Missed /1 000MH	MuARR (95 % CI)	p-value	Training Injuries: Matches Missed M (IQR)	∑ Match Oppor-tunities	∑ Matches Missed	MuA (%)	Ø Match/ Injury	Match Missed /100PS	MuARR (95 % CI)	p-value
GK	10.7	4.0 (2.0–8.0)	13 124.0	431.0	2.0	5.7	39.2 (35.5–42.9)	0.86 (0.67–1.10)	0.83	3.0 (1.0–7.5)	13 124.0	975.0	7.4	6.0	252.6 (236.7–268.5)	0.90 (0.74–1.15)	0.49
cDF	18.6	3.0 (2.0–6.0)	21 284.0	1662.0	7.8	6.0	74.6 (71.0–78.2)	1.37 (1.13–1.66)	0.003	3.0 (1.0–6.0)	21 284.0	2305.0	10.8	5.6	368.2 (353.2–383.2)	1.18 (0.97–1.41)	0.09
wDF	16.5	3.0 (1.0–6.0)	16 762.0	1008.0	4.7	5.8	59.4 (55.7–63.0)	1.14 (0.93–1.40)	0.17	3.0 (1.0–8.0)	16 762.0	1765.0	10.5	6.1	358.0 (341.3–374.7)	1.19 (0.97–1.45)	0.09
cMF	18.5	3.0 (1.0–6.0)	30 464.0	2296.0	10.8	6.4	78.0 (74.8–81.2)	1.48 (1.23–1.77)	0.000	3.0 (1.0–7.0)	30 464.0	3 345.0	11.0	5.8	373.3 (360.6–386.0)	1.21 (1.02–1.43)	0.03
wMF	18.8	3.0 (2.0–7.0)	15 776.0	1145.0	5.4	6.2	80.7 (76.0–85.4)	1.45 (1.18–1.78)	0.003	2.0 (1.0–6.0)	15 776.0	1824.0	11.6	6.1	393.1 (375.1–411.1)	1.26 (1.04–1.54)	0.02
FW	15.2	3.0 (1.0–6.0)	18 224.0	1040.0	4.9	5.2	63.6 (59.7–67.5)	1.00 (reference)		2.0 (1.0–5.0)	18 224.0	1728.0	9.5	4.9	322.4 (307.2–337.6)	1.00 (reference)	

MuA = Match un-availability; M = Median; IQR = Inter-quartile range; IR = Incidence Rate; MuARR = Match un-availability rate ratio; CI = Confidence Interval; GK = Goal keeper; cXX/wXX = Central/Winger; DF = Defender; MF = Midfielder; FW = Striker

tance and was assumed, in the absence of clearance to access medical information, to be a trustworthy alternative.

Despite these measures, the incidence of match injuries recorded (11.5/1 000 match-hours) appears to be lower compared to previous rates observed by Faude et al. [19] (37.5/1 000 match-hours) and aus der Fünten et al. [6] (20.7–22.3/1 000 match-hours). This discrepancy might be attributed to a number of methodological aspects. Particularly, since information about injuries is obtained from the mass media, it might be plausible that the rate of minor and mild traumatic injuries such as contusions, lacerations and minor hematomas are under-reported and hence missing from our register. These injuries do not prevent players from participating in training or matches. Another potential explanation for the low incidence rate of match-injuries might be accounted for by the high match exposure time documented in our register (18 582 match-hours/season). Faude et al. [19] reported match exposure of 11,765 h per season, while based on aus der Fünten et al. [6] data we may estimate a match exposure rate of 14 099 match-hours per season from all 18 clubs.

The overall injury incidence was around 99 injuries per 100 player-seasons. On average, one injury is diagnosed per player per season in a 1BL squad. A quarter (25 %) of these injuries will be minimal and mild, causing an absence of one week. The medical staff can expect each season around 10 moderate (recovery > 7–27 days) and 9 severe injuries causing absences of more than 4 weeks. We identified slightly higher rate of severe injuries compared to Faude et al. [19] and aus der Fünten et al. [6] indicating 7.6 and 6.2 injuries per season assuming a squad of 25 players, respectively, and a slightly lower rate of moderate injuries (12 and 16 injuries per season respectively). The impact an injury has on a club can be considered in terms of the number of days absent and potential competitive matches missed. On average, 18.0 days and 3.0 matches were missed per injury, slightly higher than the previously reported lay-off time of 14.5 days per injury in the 1BL [19] but lower compared to English professional footballers with a lay-off time of 24.2 days and 4.0 matches per injury [27].

When considering the findings of injury type and localization patterns in this study, it is important to bear in mind that, due to unspecified exact diagnosis in the injury reports regarding type and the associated body part of an injury, about one third of all injuries were unclassified according to type (31.4 %) and localization (27.5 %). This decreases the possibility to ascertain an accurate picture of injury patterns. Our findings indicate an inconsistent pattern with a clear predominance of muscle injuries in total. On the other hand the knee – which corresponds to a joint/ligament injury type – was found to be the body part sustaining the highest injury risk. Nevertheless, our findings demonstrate a pattern of predominately muscle strains followed by ligament sprain which seem to be in agreement with previously reported injury patterns in the 1BL [19].

In reference to moderate and severe injuries, based on our findings, medical practitioners in a 1BL squad (25 players) may expect in a season an average of 7.6 moderate muscle strains, around 2.8 of which affect the hamstring or adductor muscle group, 1 severe tendinopathy, potential to the groin or Achilles tendon, and 4 severe, potential grade 2 or 3 ligament sprains, of which around 2 may affect the ankle. Also one knee cruciate ligament (KCL) rapture might be expected, but every second year. These findings are within range of previous observed values of around 5.6–11.2 moderate muscle strains and 2.9–3.9

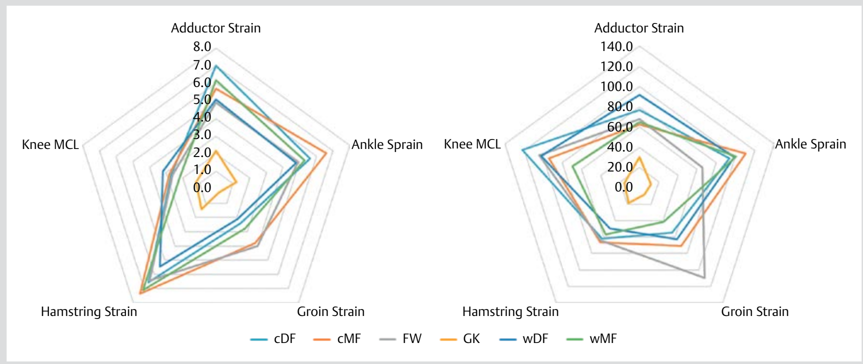

Fig. 1 Injury profiles of positional roles. Left panel illustrates the injury incidence (per 100 player seasons). Right panel illustrates the injury burden (days missed/100 player-seasons)

severe ligament sprains per squad per season reported in the Bundesliga [6, 19].

Hamstring strain was the single most common injury observed, which is in agreement with others [16, 36] probably reflecting the velocity of play in the 1BL. Previous values from English and Australian professional football indicating 5–6 hamstring strains per team per season, resulting in an absence rate of 18 days and 3–3.5 matches per strain [35, 49]. Evidence from the UEFA Champion League indicating a slightly higher 6–7 hamstring strains per team per season [26]. Data from the Bundesliga found on average 5.5 hamstring strains per team per season [6], higher than the value observed in this work. However, the lay-off time of 10.6 days on average per strain is in agreement to the values we observed. Our observed lay-off time from both muscle strain (14.5 days, 2.5 matches) and ligament sprain (32.75 days, 4.5 matches) seems to be slightly higher compared to previous reports in the 1BL, indicating 10.5 and 27.5 days on average following a strain and sprain, respectively [19]. In total, 77 KCL raptures were recorded, indicating on average 12.8 raptures per season. Owing to an unspecified diagnosis as the exact ligament in question (anterior or posterior cruciate ligament), care should be taken when comparing results from studies, only documenting ACL rapture data. Evidence indicate that in soccer, a lesion to the posterior cruciate ligament (PCL) is much less common compared to ACL [32]. An audit of KCL rapture among 3rd division Bundesliga players found that only 2.0 % of all KCL affect the PCL [32]. The expected rate of 0.56 KCL injuries observed per squad of 25 players per season is slightly lower than the previously reported rate of 0.64 ACL lesions in 1BL by Faude et al. [19] and 0.67 indicated by aus der Fünten et al. [6].

In addition, among match injuries we observed lower incidence rate (0.36/1 000 match-hours) of KCL raptures compared to the documented rate of 0.77 ACL raptures per 1 000 match-hours previously reported from the Bundesliga [6]. These values appear to be much higher compared with the 3rd division of the Bundesliga documenting an incidence rate of 0.36 KCL raptures/1 000 match-hours [32]. In terms of recovery time, our data indicating an average of 198 days and 25 matches is in agreement with previous reported data of 188 days per ACL injury from the 1BL [19].

The relatively short lay-off time (on average 30 days) following traumatic fractures might owe to fractures that did not prevent players from training or playing, such as those affecting the nose or the rib. Among all fractures identified, aus der Fünten et al. [6] indicated that only 26 % involved a lay-off time greater than 28 days. Faude et al. [19] found slightly higher values of 32 %. However, care should be taken since in this study the fracture category was merged with other types of bone injury prevalent in soccer such as Osgood-Schlatter and periostitis. Stress fractures were reported not to be common among footballers but were indicated to take a long time to heal [17]. An UEFA Injury audit showed that not even one single stress fracture per every third season can be expected in a team of 25 players [17]. However once diagnosed, it was reported that it may cause an absence of 3–5 months [17]. Our data are in agreement with the frequency, indicating a single stress fracture per team only every sixth season. However we had found players to sustain a slightly shorter absence on average of around 2 months and 8 matches. Finally, although lesions to the meniscus and the cartilage were also not relatively frequent, the extensive lay-off duration (> 80 days and 10 matches) following these may owe to intense rehabilitation after surgical intervention such as arthroscopy or partial meniscectomy aiming to restore and preserve function, alleviate pain and minimize progression to osteoarthritis [18].

Several previous studies have examined the relationship between the incidence of injury across the different playing positions, and with the exception of a few studies [10, 13, 28] the injury-risk has been shown to differ [9, 19, 40]. Dauty & Collon indicated no significant difference between injury rates across the different playing positions among French professional football players [10]. However, there was a trend towards an increase incidence rate among defenders, followed by goalkeepers and forwards. Other studies have found forwards to sustain the highest injury risk [9]. Previous data from the 1BL indicated that goalkeepers had a significantly lower injury incidence compared to field players [19]. However, there were no statistical significant differences in the rates for outfield players; forwards sustain the highest injury rate followed by midfielders and defenders, respectively [19]. All studies described above, with the exception of Carling et al. [9], indicate injury-risk across outfield playing positions without sub-classifying the exact playing position, such as central-defender, left wing, etc. Specifying the exact positional role of a player is important, since evidence indicated that each playing position requires unique technical, physical and tactical demands [11, 12]. At a specific age of development, players select together with their coach the preferred playing position and learn to acquire motor skills for harnessing the demands that each positional role requires [21]. Techniques developed for load monitoring, such as movement classifications based on time-motion analysis, provide the technical team with valuable insight into the physical demands of each positional role and were also implemented previously for the analysis of injury-risk [39]. To exemplify, results based on work-rate analysis in the Spanish Premier League reveals that wing-midfielders cover significantly longer distances with the ball and perform significantly more sprints compared with central-midfielders

Table 5 Positional roles injury profiles risk ratios for injury incidence.

	Adductor Strain		Hamstring Strain		Groin Strain		Knee MCL		Ankle Sprain	
	IRR (95% CI)	**p-value**	**IRR (95% CI)**	**p-value**	**IRR (95% CI)**	**p-value**	**IRR (95% CI)**	**p-value**	**IRR (95%CI)**	**p-value**
Overall		0.121		0.038 *		0.026 *		0.161		0.341
GK	0.29 (0.11–0.56)	0.004 *	0.16 (0.03–0.36)	0.000 *	0.04 (0.03–0.44)	0.009 *	0.43 (0.23–1.31)	0.150	0.29 (0.06–0.67)	0.022 *
cDF	1.00 Reference		0.79 (0.52–1.25)	0.468	0.56 (0.34–1.17)	0.274	0.84 (0.30–1.31)	0.550	0.77 (0.48–1.39)	0.228
wDF	0.71 (0.38–1.09)	0.144	0.70 (0.56–1.23)	0.238	0.43 (0.17–0.96)	0.049 *	1.00 Reference		0.49 (0.20–1.04)	0.121
cMF	0.79 (0.41–1.08)	0.184	1.00 Reference		0.92 (0.51–1.60)	0.776	0.91 (0.49–1.59)	0.872	1.00 Reference	
wMF	0.80 (0.44–1.24)	0.227	0.90 (0.58–1.30)	0.450	0.79 (0.31–1.49)	0.290	0.59 (0.31–1.29)	0.235	0.74 (0.31–1.48)	0.555
FW	0.68 (0.38–1.45)	0.483	0.77 (0.43–1.33)	0.180	1.00 Reference		0.79 (0.33–1.11)	0.441	0.58 (0.26–1.08)	0.106

GK = Goalkeeper; cXX/wXX = Central/Winger; DF = Defender; MF = Midfielder; FW = Striker; IRR = Incidence Rate Ratio; CI = Confidence Interval; MCL = Medial Collateral Ligament

* $p < 0.05$

[12]. This is of particular importance since the mechanism of hamstring strains is associated with eccentric overload of the muscle-tendon junction emerging during maximal sprinting activities [36]. Owing to different work-rate patterns expected in the 1BL, our findings do not support the pattern identified for the Spanish Premier League – which indicates a significant injury risk associated with a hamstring strain among wing-midfielders compared to other positions. It was previously suggested that different leagues require different physical characteristics from their players [11]. Thus, different demands are placed on the playing positions. Hence, comparing results of time-motion patterns in conjunction with injury data from different leagues is not warranted and should only be done with extreme caution. We had found a significantly higher incidence rate of groin strains among forwards compared to wing-defenders. Muscular imbalance and/or insufficiency had been previously attributed to groin strain injuries [24]. However, it remains to be examined if indeed there are differences in these risk-factors for forwards and wing-defenders. We hypothesize that unique movement patterns among these 2 positional roles may explain the differences in risks. Therefore, owing to a lack of evidence, further research is warranted to examine 1) if there are differences in movement patterns such as jumping, accelerations, decelerations, sharp path changes and turning among these positional roles in the 1BL, and 2) how these events may alter the load on the musculotendinous junction. For example, considering turning, it might be expected that sharp path changes may induce excessive loads on the musculotendinous junctions specifically under the influence of fatigue.

From an incidence rate perspective, our results indicate that wing-midfielders have the highest incidence of match injuries, while central-defenders and wing-midfielders are exposed to the highest incidence of training injuries. However, in order to obtain a more comprehensive understanding of how injury magnitude affected return to play, the dependent variables injury burden and match unavailability were implemented as separate outcome measures. We observed a significant difference in the lay-off time across different positional roles. Midfielders and central-defenders sustained significantly more days of absence per 1 000 match-hours due to a match injury compared to forwards. In addition, players filling those positional roles have shown significantly higher unavailability rates for matches due to a match injury compared to forwards. These findings are noteworthy since they may have potential implication from a number of perspectives. From a performance point of view, managers may have difficulties in assigning the best players to these positional roles, especially since these playing positions are the linking chain for the whole team. Central-defenders, for example, often perform long passes to midfielders to create scoring opportunities. Therefore, dis-coordination between central-defenders and midfielders as a result of frequent change in players might significantly impair communication and ultimately performance, resulting in a reduction of technical skill (e.g., more unsuccessful passes). However, care should be taken when interpreting the results since we might over-estimate the match opportunities, not accounting for the possibility that a player might be prevented from playing due to other reasons than being injured (e.g., due to an illness, losing their place in the squad or personal reasons).

In addition, from a rehabilitation perspective, match availability not only provides a measure for scaling a manager's ability to assemble the best squad as was previously introduced by Hägglund et al. [25], but may also be used as an instrument for estimating how a variety of factors may limit a player's successful rehabilitation. A prolonged absence from matches may dramatically diminish a player's self-esteem with other possible negative psychological effects for the individual player and the team as a whole (for a comprehensive review of the psychological impact of injuries on athletes see: Smith [41]). Team cohesion develops as part of player's interaction on the pitch during matches. The collective success created on the pitch during games plays a cardinal role in a player's positive morale, for building a player's confidence in their performance capabilities and, ultimately, for delivering the best possible performance. Player unavailability to matches due to an injury may create psychological barriers that directly result in reduced performance and movement control, ultimately leading to an increase injury-risk, even after clearance for return to play is officially granted by the medical team. Therefore, practitioners may need to take special precautions in order to provide conditions that will facilitate recovery from the negative side-effects that central-defenders and midfielders may experience as a consequence of the inability to train and play for prolonged periods of time. Towards the end phase of tissue healing, for instance, athletic trainers and physical therapists may design specific training sessions as part of small-sided-games with the aim of enhancing player decision making and possibly increasing a player's self-confidence among other factors.

Perspective

▼

In conclusion, an audit of injury-risk based on information from public media might have advantages as it may be possible to analyze large and complete populations using a longitudinal design. Permitting non-intrusive access to medical documentation and data obtained independent of individual or team compliance. However, a major disadvantage is the lack of information about the reliability and validity of the injury and exposure time data. Nevertheless, the results of this study provide a picture of the types, locations and severity of injuries emerging among Bundesliga players. To the best of our knowledge, this is the first study to provide indirect evidence that specific playing positions might be more affected by the negative consequences of injuries than others. This information might be of great importance to medical practitioners, since rehabilitation prognoses, adherence to and compliance with rehabilitation goals depends to a large extent on an athlete's psychological state. These results may also enable tailored preventive measures. Further research is, however, needed to assess which specific physiological, psychological or technical components may lead to this risk difference. Second, if indeed our findings based on epidemiological data correspond to a more direct analysis of the psychological impact of injuries on players in high-risk positions, we can more effectively assist these injured athletes by helping to prevent them from entering the continuum of disability cycle.

Acknowledgements

▼

Special thanks must go to Dr. Kathrin Beier MD for proofing that all original medical information retrieved in German was correctly translated into English. Special thanks must also go to TUM English Writing Centre for the assistance in proofing the language of the final manuscript draft.

Conflict of interest: The authors have no conflict of interest to declare.

References

1 *Altman DG*. Practical statistics for medical research. 1st ed. London: Chapman and Hall; 1991
2 *Aragon TJ*. epitools: Epidemiology Tools. R package 2012; version 0.5–7 http://CRAN.R-project.org/package=epitools
3 *Ardern CL*, *Taylor NF*, *Feller JA*, *Webster KE*. Fear of re-injury in people who have returned to sport following anterior cruciate ligament reconstruction surgery. J Sci Med Sport 2012; 15: 488–495
4 *Ardern CL*, *Webster KE*, *Taylor NF*, *Feller JA*. Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery two-thirds of patients have not returned by 12 months after surgery. Am J Sports Med 2011; 39: 538–543
5 *Arnason A*, *Sigurdsson SB*, *Gudmundsson A*, *Holme I*, *Engebretsen L*, *Bahr R*. Risk factors for injuries in football. Am J Sports Med 2004; 32: 5S–16S
6 aus *der Fünten K*, *Faude O*, *Lensch J*, *Meyer T*. Injury characteristics in the German professional male soccer leagues after a shortened winter break. J Athl Train 2014; 49: 786–793
7 *Bjørneboe J*, *Bahr R*, *Andersen TE*. Gradual increase in the risk of match injury in Norwegian male professional football: A 6-year prospective study. Scand J Med Sci Sports 2014; 24: 189–196
8 *Bjørneboe J*, *Flørenes TW*, *Bahr R*, *Andersen TE*. Injury surveillance in male professional football; is medical staff reporting complete and accurate? Scand J Med Sci Sports 2011; 21: 713–720
9 *Carling C*, *Orhant E*, *LeGall F*. Match injuries in professional soccer: inter-seasonal variation and effects of competition type, match congestion and positional role. Int J Sports Med 2010; 31: 271–276
10 *Dauty M*, *Collon S*. Incidence of injuries in French professional soccer players. Int J Sports Med 2011; 32: 965–969
11 *Dellal A*, *Wong DP*, *Moalla W*, *Chamari K*. Physical and technical activity of soccer players in the French First League-with special reference to their playing position: Original research article. ISMJ 2010; 11: 278–290
12 *Di Salvo V*, *Baron R*, *Tschan H*, *Calderon Montero F*, *Bachl N*, *Pigozzi F*. Performance characteristics according to playing position in elite soccer. Int J Sports Med 2007; 28: 222–227
13 *Dvorak J*, *Junge A*. Football injuries and physical symptoms a review of the literature. Am J Sports Med 2000; 28: S3–S9
14 *Ekstrand J*. Soccer injuries and their prevention" (doctoral dissertation). Linköping University 1982
15 *Ekstrand J*. Keeping your top players on the pitch: The key to football medicine at a professional level. Br J Sports Med 2013; 47: 723–724
16 *Ekstrand J*. Playing too many matches is negative for both performance and player availability – results from the on-going UEFA injury study. Dtsch Z Sportmed 2013; 2013: 5–9
17 *Ekstrand J*, *Torstveit M*. Stress fractures in elite male football players. Scand J Med Sci Sports 2012; 22: 341–346
18 *Falah M*, *Nierenberg G*, *Soudry M*, *Hayden M*, *Volpin G*. Treatment of articular cartilage lesions of the knee. Int Orthop 2010; 34: 621–630
19 *Faude O*, *Meyer T*, *Federspiel B*, *Kindermann W*. Injuries in elite German football: A media-based analysis. Dtsch Z Sportmed 2009; 60: 139–144
20 *Fuller CW*, *Ekstrand J*, *Junge A*, *Andersen TE*, *Bahr R*, *Dvorak J*, *Hägglund M*, *McCrory P*, *Meeuwisse WH*. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Scand J Med Sci Sports 2006; 16: 83–92
21 *Gil SM*, *Gil J*, *Ruiz F*, *Irazusta A*, *Irazusta J*. Physiological and anthropometric characteristics of young soccer players according to their playing position: relevance for the selection process. J Strength Cond Res 2007; 21: 438–445
22 *Hägglund M*, *Waldén M*, *Ekstrand J*. Injury incidence and distribution in elite football – a prospective study of the Danish and the Swedish top divisions. Scand J Med Sci Sports 2005; 15: 21–28
23 *Hägglund M*, *Waldén M*, *Ekstrand J*. Injuries among male and female elite football players. Scand J Med Sci Sports 2009; 19: 819–827
24 *Hägglund M*, *Waldén M*, *Ekstrand J*. Risk factors for lower extremity muscle injury in professional soccer the UEFA injury study. Am J Sports Med 2013; 41: 327–335
25 *Hägglund M*, *Waldén M*, *Magnusson H*, *Kristenson K*, *Bengtsson H*, *Ekstrand J*. Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. Br J Sports Med 2013; 47: 738–742
26 *Hallén A*, *Ekstrand J*. Return to play following muscle injuries in professional footballers. J Sports Sci 2014; 32: 1229–1236

27 *Hawkins R*, *Hulse M*, *Wilkinson C*, *Hodson A*, *Gibson M*. The association football medical research programme: an audit of injuries in professional football. Br J Sports Med 2001; 35: 43–47
28 *Hawkins RD*, *Fuller CW*. An examination of the frequency and severity of injuries and incidents at three levels of professional football. Br J Sports Med 1998; 32: 326–332
29 *Hawkins RD*, *Fuller CW*. A prospective epidemiological study of injuries in four English professional football clubs. Br J Sports Med 1999; 33: 196–203
30 *Jacobson I*, *Tegner Y*. Injuries among female football players-with special emphasis on regional differences. Adv Physiother 2006; 8: 66–74
31 *Junge A*, *Dvorak J*. Influence of definition and data collection on the incidence of injuries in football. Am J Sports Med 2000; 28: S40–S46
32 *Krutsch W*, *Zeman F*, *Zellner J*, *Pfeifer C*, *Nerlich M*, *Angele P*. Increase in ACL and PCL injuries after implementation of a new professional football league. Knee Surg Sports Traumatol Arthrosc 2014; 1–9
33 *Kucera KL*, *Marshall SW*, *Kirkendall DT*, *Marchak P*, *Garrett WE*. Injury history as a risk factor for incident injury in youth soccer. Br J Sports Med 2005; 39: 462–462
34 *Murphy D*, *Connolly D*, *Beynnon B*. Risk factors for lower extremity injury: A review of the literature. Br J Sports Med 2003; 37: 13–29
35 *Orchard J*, *Seward H*. Epidemiology of injuries in the Australian Football League, seasons 1997–2000. Br J Sports Med 2002; 36: 39–44
36 *Petersen J*, *Hölmich P*. Evidence based prevention of hamstring injuries in sport. Br J Sports Med 2005; 39: 319–323
37 *Petersen J*, *Thorborg K*, *Nielsen MB*, *Budtz-Jørgensen E*, *Hölmich P*. Preventive effect of eccentric training on acute hamstring injuries in men's soccer a cluster-randomized controlled trial. Am J Sports Med 2011; 39: 2296–2303
38 *Pfennig CSD*, *Degenhart J*, *Hassan H*, *Herzog T*, *Lehmann JM-BD*, *Möglich W*, *Schild TSM*, *Türck M*. Bundesliga Report 2015. In. Frankfurt/Main (Germany): DFL Deutsche Fußball Liga GmbH; 2015
39 *Robinson G*, *O'Donoghue P*. A movement classification for the investigation of agility demands and injury risk in sport. Int J Perform Anal Sport 2008; 8: 127–144
40 *Ryynänen J*, *Junge A*, *Dvorak J*, *Peterson L*, *Karlsson J*, *Börjesson M*. The effect of changes in the score on injury incidence during three FIFA World Cups. Br J Sports Med 2013; 47: 960–964
41 *Smith AM*. Psychological impact of injuries in athletes. Sports Med 1996; 22: 391–405
42 *Taimela S*, *Osterman L*, *Kujala U*, *Lehto M*, *Korhonen T*, *Alaranta H*. Motor ability and personality with reference to soccer injuries. J Sports Med Phys Fitness 1990; 30: 194–201
43 *R Core Team*. R: A language and environment for statistical computing. R Foundation for Statistical Computing 2014; Vienna, Austria.URL http://www.R-project.org/
44 *van Mechelen W*, *Hlobil H*, *Kemper HC*. Incidence, severity, aetiology and prevention of sports injuries. Sports Med 1992; 14: 82–99
45 *Von Porat A*, *Roos EM*, *Roos H*. High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: A study of radiographic and patient relevant outcomes. Ann Rheum Dis 2004; 63: 269–273
46 *Waldén M*, *Hägglund M*, *Orchard J*, *Kristenson K*, *Ekstrand J*. Regional differences in injury incidence in European professional football. Scand J Med Sci Sports 2013; 23: 424–430
47 *Wiese-Bjornstal DM*, *Smith AM*, *Shaffer SM*, *Morrey MA*. An integrated model of response to sport injury: Psychological and sociological dynamics. J Appl Sport Psychol 1998; 10: 46–69
48 *Wikstrom EA*, *Hubbard-Turner T*, *McKeon PO*. Understanding and treating lateral ankle sprains and their consequences. Sports Med 2013; 43: 385–393
49 *Woods C*, *Hawkins R*, *Maltby S*, *Hulse M*, *Thomas A*, *Hodson A*. The Football Association Medical Research Programme: An audit of injuries in professional football – analysis of hamstring injuries. Br J Sports Med 2004; 38: 36–41

4.2 Study-2

Leventer L, Eek F, and Lames M. "Intra-seasonal variation of injury patterns among Ger- man Bundesliga soccer players". In: *Journal of Science and Medicine in Sport* 22.6 (2019), pp. 661- 666.

G Model
JSAMS-1995; No. of Pages 6

ARTICLE IN PRESS

Journal of Science and Medicine in Sport xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Intra-seasonal variation of injury patterns among German Bundesliga soccer players

L. Leventer[a,*], F. Eek[b], M. Lames[a]

[a] Faculty of Sport and Health Sciences, Technische Universität München, Munich, Germany
[b] Department of Health Sciences, Lund University, Lund, Sweden

ARTICLE INFO

Article history:
Received 27 July 2018
Received in revised form
29 November 2018
Accepted 2 December 2018
Available online xxx

Keywords:
Epidemiology
Injury patterns
Injury incidence
Time-loss injury

ABSTRACT

Objective: High fluctuations in injury-risk during the playing season in soccer have been reported. As seasons are structured in periods with homogenous loads and intensities, we investigated injury-risk over season periods, contrarily to previous studies adopting a month-based approach.
Design: Cohort study; Level of evidence, 2.
Methods: Incidence-rate ratios (IRRs) for match and training injuries were compared across six consecutive seasons of German Bundesliga, divided into six periods each: Pre-season (PS), winter-break (WB), quarter 1–4: (Q1–Q4).
Results: Significant variations in injury-risk were observed for match and training injuries. IRRs in matches was 1.30 (95% CI: 1.11–1.53) times higher in Q3 and 1.53 (95% CI: 1.31–1.78) higher in Q4 compared to Q1. For training injuries, IRR peaked in Q1 and Q3 followed by a marked decrease in each subsequent quarter. Compared to Q4, IRR was 1.62 (95% CI: 1.40–1.86) times higher during Q3 and 1.78 (95% CI: 1.53–2.07) times higher in Q1. IRR was significantly higher in the competitive season compared to pre-season across match (IRR: 2.00, 95% CI: 1.30–3.00) and training (IRR: 1.27, 95% CI: 1.11–1.43) injuries.
Conclusions: The increased match IRRs later during the season indicate that, in practice, coaches should consider putting even more emphasis on recovery in the last part of the season. Moreover, training injuries seem to indicate a carry-over effect. Further studies need to investigate how training during preparatory phases can be implemented in a way that prevents injuries during the competitive season.

Practical implications

- The increased match incidence-rate evident throughout the season calls for the need to consider putting even more emphasis on recovery by the technical team towards the latter part of the season.
- Further studies need to confirm if indeed players train in the preparatory phases in ways that might predispose them to an increase injury-risk as observed by the carry-over effect.
- Actual values describing variations of injury-risk across season periods provided may allow the medical team insight necessary for enhancing injury management systems with the aim of alleviating injuries in contemporary professional soccer.

1. Introduction

At a professional level, the primary objective of a soccer club is success on the pitch. Success is linked to state-of-the-art facilities, coaching, management, talented, well-trained and above all, healthy players. High physiological, psychological, technical and tactical demands predispose players to a substantial injury risk. The risk of injury is estimated to be about 1000 times higher compared to industrial jobs regarded as high risk occupation[1]. As presented by Ekstrand, Dvorak, D'hooghe[2], considering professional players as employees, their current working condition in a team can equate to eight new injuries each week in a staff of 25 employees working full time (40 h per week). This hazard is especially alarming owing to the fact that this group contains over 60,000 professional soccer players worldwide.

Injury risk has been reported to vary considerably over the months of the season[3–5]. In some studies the difference between the highest (April) and the lowest (September) injury count in the competitive season was 150%[3,4]. Many reasons might account for these variations, e.g. accumulated fatigue as the season unfolds[6],

* Corresponding author.
E-mail address: louis.leventer@tum.de (L. Leventer).

https://doi.org/10.1016/j.jsams.2018.12.001
1440-2440/

reduced concentration resulting in decision making errors leading to match injuries[7], and critical play behavior such as duels and fouls increasing throughout the season[8].

This study suggests dividing the season into periods rather than into months as done until now when investigating the course of injuries over a season[3–5]. In line with the concept of periodization[9], professional soccer clubs organize the season into preparatory and competition periods[10]. Each of these periods has a unique profile in terms of work-recovery ratio, match/training ratio and friendly/competition match ratio, which is likely to directly influence injury characteristics. For example, the incidence rate of muscle strains was found to be highly correlated with players conditioning as indicated by an increase in average heart-rate in the Spanish La-Liga season period[5]. Training load data in the English Premier League indicated that average heart-rate values were significantly higher in the 3rd (end of first season halve) and 6th (last part of season) mesocycle of the season than in the first, with results indicating moderate effect size[11]. This example demonstrates how periodization can influence injury-risk.

The current study aims to describe and compare the pattern of match and training injury incidences among elite soccer players in the German Bundesliga during preparatory and competitive periods of the season. Specifically, we attempt to study the pattern of match and training incidence-rate (IR)'s across season periods and to investigate whether different injury types show different IR variations throughout season periods.

2. Method

This cohort study includes all male players with a first team contract in one of the 18 clubs in the 1st division of the German Bundesliga, over six competitive seasons (n = 1448). Injury and exposure data was recorded per player and was retrieved from a media-base register (www.transfermarkt.de), previously used in a study on injury-risk we conducted[12].

The data was acquired by an independent data scientist, who was not involved in analytics but developed a web-scrapper algorithm which extracted raw data from the register. Because data is based on the media, we performed some special measures, described in detail in our previous study[12], to verify the quality of the data. Injury diagnosis was translated from German to English and proofed by a medical doctor with native proficiency in both languages. A quality control phase was thereafter initiated by the first author (LL), a sports physiotherapist. In inconclusive cases, decision on injury data was made after advising with the second author (FE), also a registered physiotherapist. Following a quality control phase, data internal and external validity was assessed through reliability and cross-validation testing. Results indicated high agreement between the media-register and other two independent sources[12].

Players on trial or youth players without a professional contract were excluded. The study includes injury and exposure data from the 2008 to the 2014 season (July through May), as well as data from the preseason and winter-break period. Data from friendly matches, international duty (involving playing at the national team) and cup competitions together with official league matches were included in the analysis. Exclusion criteria accounted for exposure and injury data after the end point (official 34th Bundesliga match) of each respective season. This criterion slightly differs from our previous study[12].

After an off-season break, typically a Bundesliga season commences with a preparation phase. Then, the competition period starts with an interruption at around Christmas break for between 4 to 6 weeks, used first for recovery, and then for physical preparation. The second half of the competitive season takes place from January/February to May/June. Since the two competition subperiods last around 4 months, it is appropriate to differentiate two halves in order to distinguish periods with more or less accumulated fatigue. This leads to a competition period structure of four quarters (Q1 to Q4). The 4 period lengths were calculated in number of weeks per season according to the following criteria:

- Preseason: from 1st July–1st official Bundesliga match
- Q1: 1st–7th Bundesliga matches
- Q2: 8th–17th Bundesliga matches
- WB: from the second day after the 17th match till the first day prior to the 18th Bundesliga match
- Q3: 18th–26th Bundesliga matches
- Q4: 27th–last (34th) Bundesliga matches

A time loss definition was adopted according to the consensus statement for injury definition in studies of soccer injuries[13]. Therefore, an injury was recorded if the player was unable to fully participate in soccer activity or match play due to any musculoskeletal disorders at least one day beyond the reported day of injury. The player was considered injured until his reported end day of injury, or alternatively until the first match played which he participated in. An injury was classified as match injury if reported on the same or the following day of a match in which the player was playing. A training injury was defined as an injury reported on any other day than a match injury occurred[12].

Exposure time was calculated separately for match and training injuries. For match injuries, player exposure was based on actual playing time in minutes. Due to lack of information regarding exposure time in minutes per player per training session, person-time was measured as player-week for training injuries. Descriptive results were presented in IRs with corresponding 95% confidence intervals (CI). IRs were calculated separately for match and training, and reported as injuries per 1000 match-hours for match injuries and injuries per 100 player-weeks for training injuries. Generalized linear mixed-effects models by maximum likelihood were fitted with each player injury count as a dependent variable, period of the season as an independent variable and time under risk (minutes played on weeks exposed) as an offset. In addition, a categorical variable injury type coded as either of the following: (1) muscle/tendon, (2) joint/ligament or (3) contusion/laceration was included in the model for the analysis of injury type through an interaction. An interaction term was added to test the hypothesis if the pattern of IRs throughout the season periods were significantly different across different injury types. Furthermore, the model included a random intercept, accounting for each player and each season. Assigning player id and season as a random intercept in a GLM mixed-effect model allows estimating coefficients of season periods accounting for potential individual and seasonal differences between players and between seasons[14]. These models were implemented for determining changes in incidence rate-ratio (IRR) throughout the different periods of the season. The first and second halve categories were created by aggregating Q1–Q2 and Q3–Q4. Also, the competitive season category was established by aggregating each quarter Q1–4 when comparing with PS and WB.

The calculation of type 2/3 analysis-of-variance was implemented using Wald chi-square tests in order to affirm for overall significance of regression models. A dispersion test was carried out to check for over-dispersion, hence selecting between a Poisson and negative binominal distribution when appropriate[15].

Alpha was deemed to be significant if p-value was below 0.05. Data preparation and analysis was performed entirely in R[16] using the AER[17], car[15] and lme4[18] packages.

Please cite this article in press as: Leventer L, et al. Intra-seasonal variation of injury patterns among German Bundesliga soccer players. *J Sci Med Sport* (2018), https://doi.org/10.1016/j.jsams.2018.12.001

3. Results

A total exposure of 114,637 player-weeks was recorded during the 6-year long study period. Exposure during matches accounted for 101,016 match-hours. A total of 3438 injuries was documented; 1397 (40.6%) match injuries and 2041 (59.4%) training injuries. The overall injury incidence during the study was 2.8 (95% CI: 2.7–2.9) injuries per 100 player-weeks. The incidence-rate for match injuries was 13.8 (95% CI: 13.1–14.6) per 1000 match-hours and for training injuries 1.8 (95% CI: 1.7–1.9) per 100 player-weeks.

Fig. 1 shows the distribution of injury incidence across the different periods of the seasons for match and training injuries. The difference in injury-risk between the two halves of the season were statistically significant for match ($X^2 = 50.2$, df = 1, $p < 0.001$) but not for training injuries. The risk of sustaining a match injury during the second part of the season was 1.4 (95% CI: 1.2–1.5, $p < 0.001$) times higher compared to the first half (reference category).

Dissecting the season into 4 quarters, the differences in injury-incidence over season periods were significant for both match and training injuries (for match: $X^2 = 56.3$, df = 5, $p < 0.001$; for training: $X^2 = 108.0$, df = 5, $p < 0.001$). Among match injuries, the risk seems to gradually increase throughout the quarters of the season. Comparing the quarter of lowest incidence-rate (Q1) as a reference category, the incidence rate ratio during Q3 and Q4 were both statistically significant, 1.3 times higher (95% CI: 1.1–1.5, $p < 0.01$) in Q3 and 1.5 (95% CI: 1.3–1.8, $p < 0.001$) in Q4 respectively. For training injuries, incidence-rate peaked in Q1 and Q3 followed by a marked decrease in each subsequent quarter. Taking the lowest incidence-rate (Q4) as a reference category, IRR was 1.6 (95% CI: 1.4–1.9, $p < 0.001$) times higher during Q3 and 1.8 (95% CI: 1.5–2.1, $p < 0.001$) times higher in Q1 (Table 1).

Significant differences in risk were observed between the pre-season, winter-break and the competitive season for both match and training injuries (match: $X^2 = 18.7$, df = 2, $p < 0.001$, training: $X^2 = 14.3$, df = 2, $p < 0.001$). For match injuries, IRR values showed a 2.0 (95% CI: 1.4–3.0, $p < 0.01$) fold increase of risk during the competitive season compared to the pre-season. In addition, the risk of sustaining an injury during the competitive part of the season was 3.2 (95% CI: 1.2–8.6, $p < 0.05$) times higher compared to the winter-break. No significant difference was indicated when comparing the risk players sustained between the preseason with the winter-break ($p = 0.40$).

For training injuries, the risk of sustaining an injury in the competitive season was 1.3 (95% CI: 1.1–1.4, $p < 0.001$) times higher compared to the pre-season. Almost the same holds for WB with risk relationship of 1.2 (95% CI: 1.0–1.5) times higher in the competitive season.

Fig. 2 shows the distribution of injury incidence across the different periods of the season in relation to injury types for match and training injuries. A significant interaction effect between season period and injury type was found among match injuries ($X^2 = 20.3$, df = 10, $p < 0.05$). In order to interpret the interaction term, stratified analysis could be performed to support the observations below. Differences in injury patterns were observed between muscle and contusions compared to sprain injuries. The risk of sustaining a muscle/contusion gradually increases throughout the season periods (excluding winter-break) while risk of sustaining a sprain decreases during the second part of each season half (Q2 and Q4) compared to the first half (Q1 and Q3).

Stratification based on injury type over season periods revealed the following risk differences for match injuries. Relative to the reference category (Q1), among muscle strain, IRR indicate no evident increase (1.1 (95% CI: 0.9–1.5, $p = 0.373$)) in Q2, but a 1.3 (95% CI: 1.1–1.7, $p < 0.05$) fold increase in risk in Q3 and 2.2 (95% CI: 1.7–2.9, $p < 0.001$) fold increase in risk in Q4. For muscle strains occurring in training, the lowest in-season injury risk was in Q2. Risk differences indicate a 1.5 (95% CI: 1.2–2.0, $p < 0.001$) fold increase in Q1, 1.4 (95% CI: 1.1–1.8, $p < 0.01$) fold increase in Q3, but no evident increase (1.1 (95% CI: 0.9–1.4, $p = 0.38$)) in Q4.

4. Discussion

The aim of the study was to explore the course of injuries over a professional Bundesliga soccer season. We introduced a period based data aggregation in contrast to a monthly unit of analysis used in previous studies[3–5]. Such aggregation reflects the notion of periodization more accurately, which conceptually differentiates the season into periods with unique profiles of characteristics relevant for injury risk, as mentioned initially. Months are not equivalent to periods, the latter ones are adopted to the time schedule of each individual season while the former do not reflect this organisation accurately. For example, in 2011/12 the season started on 5th August, while in the succeeding year it started on 27th August. In 2012, August belonged almost entirely to the preparation phase, but in 2011 almost entirely to Q1. In addition, in specific seasons January might be accounted for the most part either as a period of preparation/recovery–in 2008/9 matches started on 31th January–or as a mixed period of preparation/recovery and competition as was the case in 2009/10 when matches resumed on 15th January. By assigning each week of a season to a period, one is able to account for changes in interval duration occurring between seasons, which provides a more accurate insight into the distribution of work/recovery and competition/preparation rates throughout the season.

On the first glance, a methodology of assigning periods compared to months might be beneficial. However, its validity for the purpose of describing injury rates may be questionable. We have to acknowledge that collecting injuries per period is less fine-grained than using months as units of analysis, but we believe that this is compensated by the more uniform load profiles within a period compared to months. For example, the month of December in the Bundesliga typically contains match play as well as recovery which blurs the respective risk-factor profiles.

It is worth mentioning that, in terms of generalisability of results, of course the findings in the present study are specific to the Bundesliga, in the sense that there is specific programme to which periodization has to be fitted (each year). While there are some differences between competition calendars of different leagues (e.g. Premier League does not have a winter break), the principle of periodisation across seasons holds for each international league. The general assumption that periods have an impact on injury profiles is not challenged by the differences. However, this warrants additional investigations.

With regards to match injuries variation over season periods, with the exception of some cup matches or qualifying matches for international club tournaments (UEFA Champions and UEFA Europe league), reduced match IRs in the preseason and winter-break may be attributed to not only low number of matches and "friendlies" but also to the lower intensity of matches characterizing these periods. This pattern is in agreement with results from other studies[19].

Increase in match injury IRs during competitive season may, at least to some part, be explained by accumulation of fatigue. One study[20] aiming at explaining such increases found that accumulated stress and lack of recovery towards the end of a season was associated with high perceived physical complaints and injuries. Moreover, studies investigating the effect of congested fixtures found a fivefold increase in IRs in matches where players had four or less days of recovery compared to matches with six or more days of recovery[21]. This was said to be due to travelling and unfamiliar sleeping conditions. These factors among others are likely

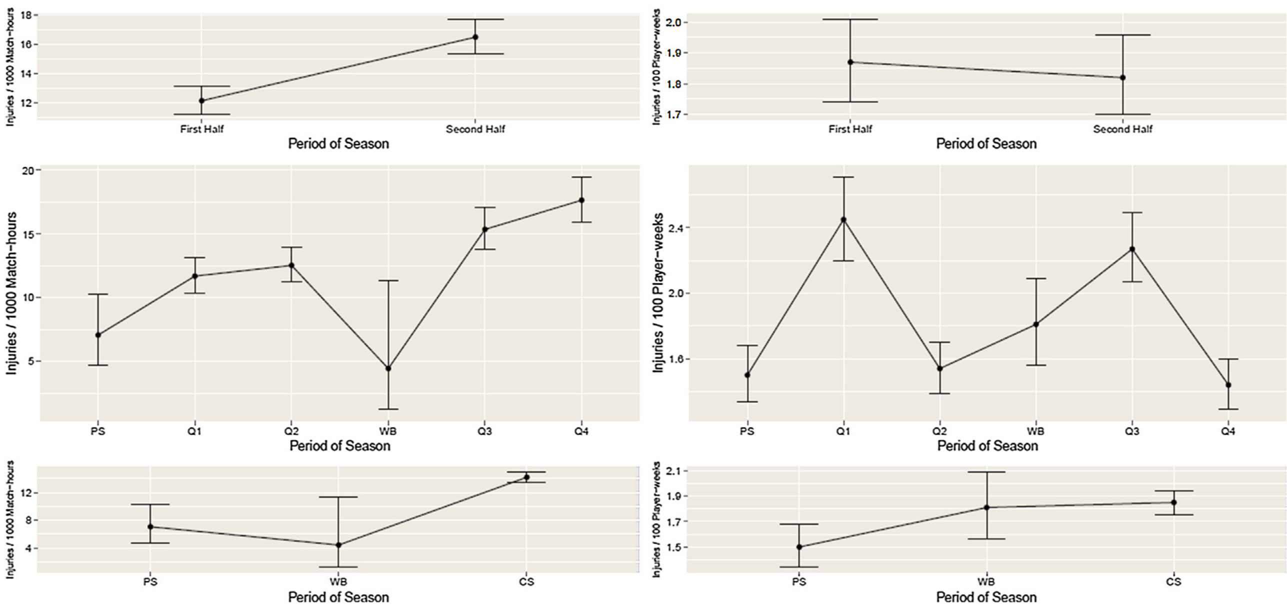

Fig. 1. Variation of injury incidence-rate across season periods for match (left panel) and training (right panel) injuries. PS = Pre-season, WB = Winter-break, CS = Competitive Season.

Table 1
Injury and exposure characteristics. *p < 0.05. **p < 0.01. ***p < 0.001.

	Preseason	Q1	Q2	Winter-break	Q3	Q4
Match						
Injuries	27	273	347	4	354	392
Exposure	3823.4	23343.9	27683.8	902.3	23040.6	22222.1
IRR (95% CI)	0.59	1.00	1.07	0.38	1.30	1.53
	(0.40–0.88)**	Reference	(0.91–1.26)	(0.14–1.02)	(1.11–1.53)**	(1.31–1.78)***
Injury type						
Muscle/tendon	8	83	112	1	109	173
Ligament/joint	12	64	67	2	78	44
Contusion/ laceration	2	23	33	1	57	78
Training						
Injuries	307	362	396	185	455	336
Exposure	20482.4	14790.9	25768.5	10216.2	20030.6	23348.1
IRR (95% CI)	1.03	1.78	1.10	1.29	1.62	1.00
	(0.88–1.20)	(1.54–2.07)***	(0.94–1.27)	(1.08–1.55)**	(1.40–1.87)***	Reference
Injury type						
Muscle/tendon	89	117	133	67	147	134
Ligament/joint	72	59	68	42	79	42
Contusion/ laceration	14	14	24	6	20	18

to cause deterioration in concentration, which may affect movement coordination and decision making, exposing players to an increase injury-risk throughout the later periods of the season. Quoting Ekstrand, Waldén, Hägglund[22]: “It may be that the major stress factor is not the 90 min of the match itself, but accumulated number of matches” (p. 495).

Another potential explanation for the increasing match injury IRs throughout the season may be accounted for by the increased number of decisive matches in the later part of the season, which, in turn, may lead to a more aggressive behaviour. Data from the Bundesliga indicate an increase in the number of fouls and duels throughout the season[8]. Foul play was previously reported to be the most important extrinsic risk factor, constituting between 12–61% of all injuries[23]. Furthermore, Junge, Dvorak, Rosch, Graf-Baumann, Chomiak, Peterson[24] found that 90% of all players were ready to commit a professional foul if required, depending on the importance of the game. As the season unfolds, the number of opportunities for securing placing on the league table decreases and therefore, each game becomes more important. Towards the end of a season, each remaining game becomes more important for the final ranking which may provoke aggression and unnecessary risk taking behavior from players.

The previous explanation is confirmed when considering match IRs patterns in different injury types. Specifically soft tissue lesions such as contusions and lacerations increase towards the end of the season when matches become more decisive, including a higher number of fouls and duels that, in turn, leads to an increase in physical contact and soft tissue trauma.

In addition, the high muscle strain IRs during matches can be explained by the hypothesis of potential increase in accumulated fatigue throughout the season. In general, there seems to be a consensus across sports medical practitioners that fatigue plays an important factor in the pathogenesis of acute muscle strains[25,26]. Fatigue had been found to decrease the ability of muscles to absorb energy, specifically in the early stages of muscle stretching which could be closely related to a decrease in muscle contractile strength[25]. Most muscle strain injuries occur when muscles are subjected to eccentric load[26–28]. The muscle contracts eccentrically until the energy in the moving limb is absorbed, and concentric contraction can start[25]. Since fatigue was found to decrease the ability

Please cite this article in press as: Leventer L, et al. Intra-seasonal variation of injury patterns among German Bundesliga soccer players. *J Sci Med Sport* (2018), https://doi.org/10.1016/j.jsams.2018.12.001

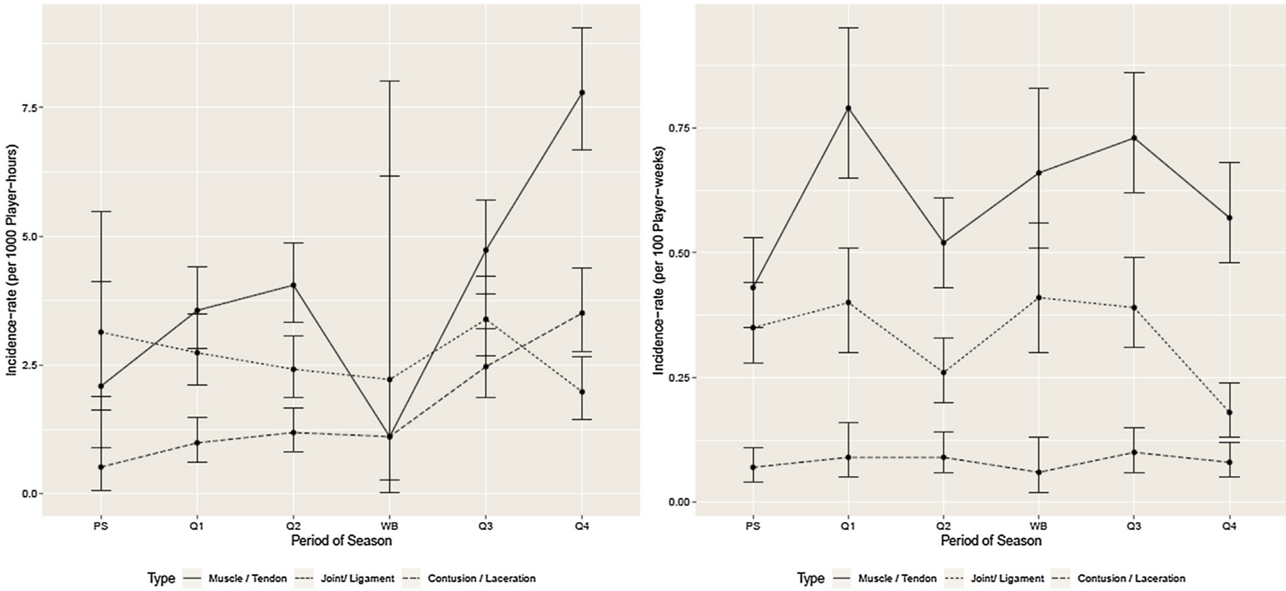

Fig. 2. Variation of incidence-rate across season periods as a function of injury typology for match (left panel) and training (right panel) injuries respectively.

of muscle to absorb energy, reduced muscular force development and contraction velocity, it is suggested to be an important factor in the aetiology and prevention of muscle injury.

With reference to training injuries variations over season periods, it is somewhat surprising that training injuries IRs peak in Q1 and Q3 whereas Match injuries peak in Q2 and Q4. This might be due to carry-over effects from the preparatory phases. In other words, the increased volume and intensity of training in the preparatory phases could potentially lead to an increase in training IRs in the first part of each competitive period, owing to a delayed effect.

A potential explanation for these carry-over effects can be due to the criteria used in the classification of an injury. Time-loss definitions adopted in this study comply with the consensus statement of soccer injuries[13]. However, as previously challenged[29], the precise onset of overuse injuries, most pronounced in training, is not captured if a time-loss definition is used to record injuries. It is likely that the pathological processes are often under way for some time before a player might notice the symptoms. Comparing time-loss injury registration and players interviews, Bahr[29] showed that players reported symptoms of pain while still taking part in training and competition, sometimes months before actual rehabilitation commenced. This shortcoming calls for the need of an alternative approach of injury reporting, which could be effective in identifying onset of overuse injuries.

Regarding the relative minima for training injuries in Q2 and Q4 one might assume that coaches might compensate for accumulated fatigue by reducing training volumes and intensity. This is meant to ensure optimal recovery for future decisive games.

Inspecting the type of injuries, we found the carry-over pattern (relative maxima in Q1 and Q3) even more pronounced for muscle and tendon injuries than in the overall training injuries pattern. This is in agreement with the hypothesized mechanism of the carry-over effect, because muscular strains and tendinopathies are primarily overuse injuries, attributed to gradual microtrauma[29]. Joint and ligament injuries IRs correspond to the general trend of muscle injuries. Contusions and lacerations do not show a very pronounced seasonal pattern. The increase of training IR evidenced in strains and sprains in the winter-break might be at least partly attributed to under-reporting of injuries from Q2 and even in Q1, due to variety of reasons, such as players fear of losing place in the team.

The recent decision of the British Premier League to introduce a winter-break from 2020 onwards is supported by the results of this study. The introduction of the winter-break is expected to have beneficial effects such as allowing for rest and recovery. The intended duration of two weeks, through seems to be too short for the purpose of implementing multicomponent preventive programs, typically requiring a minimum of between 6 to 8 weeks[30].

This study encountered a number of methodological limitations. As has been previously acknowledged[12], due to the nature of collecting data from the media, journalists or scouters may have been unaware of players' short absence from soccer participation, and therefore, injuries of minimal and minor severity are likely to be underreported, and hence expected, in part, to be missing from the register. Nevertheless, in terms of reporting bias, we expected injuries to be uniformly distributed throughout the season periods.

Unfortunately, the database does not distinguish between events occurring during international play (matches involving the national team), which makes estimating the incidence-rate affecting players in international duty difficult.

In addition, information on player team affiliation and training load were not provided. Training data is largely protected by club privacy which, given its absence, it is rather difficult to quantify load differences between clubs. It is expected that teams use different periodization strategies, according to their seasonal programs. For example, coaches might tailor their training programs differently if participating in the Champions League compared to other teams that need to consider only national competitions.

5. Conclusions

Recognising the significance of the variability in injury IR pattern across a season, from a methodological perspective, periods showed to be more promising units of analysis compared with months, where only fixed time intervals can be considered. In addition, we believe that the distinction between match and training injuries is important because findings show unique patterns each being governed by different effects, partly compensatory because training is reduced when match loads become too high.

Furthermore, even if coaches may deliberately control training load, based on the findings of increasing IR for match injuries as the season unfolds, coaches should in practice consider putting even more emphasis on recovery in the last parts of the season.

Moreover, as evident from the carry-over effect, it seems that players train in the preparatory periods in a way that predisposes them to a high injury-risk in the competitive season, which is to be avoided. If these find ings are corroborated in further studies, there is a need to rethink training methods in the preparatory period of the season.

Finally the possibility that accumulated fatigue may lead to higher match IR already after the first half season in German Bundesliga, highlights the importance of having a winter-break. Seen in this light, the recent made decision of the British Premier League to introduce a winter-break is supported by our findings.

Acknowledgments

No financial assistance with this project was given.

References

1. Drawer S, Fuller C. Evaluating the level of injury in English professional football using a risk based assessment process. *Br J Sports Med* 2002; 36(6):446–451.
2. Ekstrand J, Dvorak J, D'hooghe M. Sport medicine research needs funding: the International football federations are leading the way. *Br J Sports Med* 2013; 45(12):726–728.
3. Carling C, Orhant E, Le Gall F. Match injuries in professional soccer: inter-seasonal variation and effects of competition type, match congestion and positional role. *Int J Sports Med* 2010; 31(4):271–276.
4. Faude O, Meyer T, Federspiel B et al. Injuries in elite German football-A media-based analysis. *Dtsch Z Sportmed* 2009; 60(6):139–144.
5. Mallo J, Dellal A. Injury risk in professional football players with special reference to the playing position and training periodization. *J Sports Med Phys Fitness* 2012; 52(6):631–638.
6. Smith MR, Zeuwts L, Lenoir M et al. Mental fatigue impairs soccer-specific decision-making skill. *J Sports Sci* 2016; 34(14):1297–1304.
7. Russell M, Benton D, Kingsley M. The effects of fatigue on soccer skills performed during a soccer match simulation. *Int J Sports Physiol Perform* 2011; 6(2):221–233.
8. Link D, de Lorenzo MF. Seasonal pacing-match importance affects activity in professional soccer. *PLoS One* 2016; 11(6):e0157127.
9. Bompa T, Harf G. *Periodization training for sports: theory and methodology of training*, United State of America, Human Kinetics, 2009.
10. Mallo J. Effect of block periodization on performance in competition in a soccer team during four consecutive seasons: a case study. *Int J Perform Anal Sport* 2011; 11(3):476–485.
11. Malone JJ, Di Michele R, Morgans R et al. Seasonal training-load quantification in elite English premier league soccer players. *Int J Sports Physiol Perform* 2015; 10(4):489–497.
12. Leventer L, Eek F, Hofstetter S et al. Injury patterns among elite football players: a media-based analysis over 6 seasons with emphasis on playing position. *Int J Sports Med* 2016; 37(11):898–908.
13. Fuller CW, Ekstrand J, Junge A et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Scand J Med Sci Sports* 2006; 16(2):83–92.
14. Breslow NE, Clayton DG. Approximate inference in generalized linear mixed models. *J Am Stat Assoc* 1993; 88(421):9–25.
15. Fox J, Weisberg S. *An R companion to applied regression*, 2nd ed. Thousand Oaks CA, Sage, 2011.
16. Team RC. *R: a language and environment for statistical computing*, 3.2.3 ed. Vienna Austria, R Foundation for Statistical Computing, 2017.
17. Kleiber C, Zeileis A. *Applied econometrics with R*, 1. 2–5 ed. New York, Springer-Verlag, 2008.
18. Bates D, Maechler M, Bolker B et al. Fitting linear mixed-effects models using lme4. *J Stat Softw* 2015; 67(1):1–48.
19. Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: the UEFA injury study. *Br J Sports Med* 2016; 2009, bjsports60582.
20. Faude O, Kellmann M, Ammann T et al. Seasonal changes in stress indicators in high level football. *Int J Sports Med* 2011; 32(04):259–265.
21. Dupont G, Nedelec M, McCall A et al. Effect of 2 soccer matches in a week on physical performance and injury rate. *Am J Sports Med* 2010; 38(9):1752–1758.
22. Ekstrand J, Waldén M, Hägglund M. A congested football calendar and the well-being of players: correlation between match exposure of European footballers before the World Cup 2002 and their injuries and performances during that World Cup. *Br J Sports Med* 2004; 38(4):493–497.
23. Ryynänen J, Dvorak J, Peterson L et al. Increased risk of injury following red and yellow cards, injuries and goals in FIFA World Cups. *Br J Sports Med* 2013; 47(15):970–973.
24. Junge A, Dvorak J, Rosch D et al. Psychological and sport-specific characteristics of football players. *Am J Sports Med* 2000; 28(5_suppl):22–28.
25. Mair SD, Seaber AV, Glisson RR et al. The role of fatigue in susceptibility to acute muscle strain injury. *Am J Sports Med* 1996; 24(2):137–143.
26. Opar DA, Williams MD, Shield AJ. Hamstring strain injuries. *Sports Med* 2012; 42(3):209–226.
27. Ekstrand J, Gillquist J. The frequency of muscle tightness and injuries in soccer players. *Am J Sports Med* 1982; 10(2):75–78.
28. Hoskins W, Pollard H. The management of hamstring injury—Part 1: issues in diagnosis. *Man Ther* 2005; 10(2):96–107.
29. No injuries Bahr R. but plenty of pain? On the methodology for recording overuse symptoms in sports. *Br J Sports Med* 2009; 43(13):966–972.
30. Fünten K, Faude O, Lensch J, Meyer T. Injury characteristics in the German professional male soccer leagues after a shortened winter break. *J Athl Train* 2014; 49(6):786–793.

4.3 Study-3

Leventer L, Dicks M, Duarte R, Davids K, and Araújo D. "Emergence of contact injuries in invasion team sports: an ecological dynamics rationale". In: *Sports Medicine* 45.2 (2015), pp. 153-159.

Sports Med
DOI 10.1007/s40279-014-0263-x

CURRENT OPINION

Emergence of Contact Injuries in Invasion Team Sports: An Ecological Dynamics Rationale

Louis Leventer · Matt Dicks · Ricardo Duarte · Keith Davids · Duarte Araújo

Abstract The incidence of contact injuries in team sports is considerable, and injury mechanisms need to be comprehensively understood to facilitate the adoption of preventive measures. In Association Football, evidence shows that the highest prevalence of contact injuries emerges in one-on-one interactions. However, previous studies have tended to operationally report injury mechanisms in isolation, failing to provide a theoretical rationale to explain how injuries might emerge from interactions between opposing players. In this position paper, we propose an ecological dynamics framework to enhance current understanding of behavioural processes leading to contact injuries in team sports. Based on previous research highlighting the dynamics of performer–environment interactions, contact injuries are proposed to emerge from symmetry-breaking processes during on-field interpersonal interactions among competing players and the ball. Central to this approach is consideration of candidate control parameters that may provide insights on the information sources used by players to reduce risk of contact injuries during performance. Clinically, an ecological dynamics analysis could allow sport practitioners to design training sessions based on selected parameter threshold values as primary and/or secondary preventing measures during training and rehabilitation sessions.

L. Leventer (✉)
Chair for Top Level Sports and Sports Informatics, Faculty of Sport and Health Science, Technische Universität München, Uptown München–Campus, Georg-Brauchle-Ring 60/62, 80992 Munich, Germany
e-mail: leventer.louis@gmail.com

M. Dicks
Department of Sport and Exercise Science, University of Portsmouth, Portsmouth, UK

R. Duarte · D. Araújo
CIPER, Faculdade de Motricidade Humana, Spertlab, Universidade de Lisboa, Lisbon, Portugal

K. Davids
FiDiPro Programme, Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland

K. Davids
Centre for Sports Engineering Research, Sheffield Hallam University, Sheffield, UK

Key Points

An ecological dynamics approach proposes how information constrains coordination tendencies between competing/cooperating players and the ball, leading to changes in contact injury risks.

Future research needs to consider the information sources to which a performer needs to become perceptually attuned as affordances (possibilities for action) to decrease injury risks.

Based on identified control parameter threshold values, training and rehabilitation sessions can be designed to encapsulate specific affordances to which players may learn to become attuned in order to prevent entering high-risk injury situations.

1 Background

Team sports encompass complex performance environments in which competing players are exposed to injury

Published online: 07 October 2014

risks. For instance, in elite-level football, medical reports indicate that between 44 and 59 % of all acute match injuries are caused by contacts between opposing players during tackling and collisions [1]. Indeed, there has been an increase in the number of between-opponent contacts (heading and tackling duels) in the last decade [2].

van Mechelen et al. [3] postulated that measures to prevent sports injuries do not stand by themselves, rather, they form the 'sequence of prevention'. After the magnitude of an injury problem is established in terms of incidence and severity, it is critical to identify risk factors and mechanisms of injury. The causation model of injury occurrence suggests that the mere presence of intrinsic (player characteristics) and extrinsic (environmental characteristics) risk factors is not sufficient to produce an injury [4]. Rather, the sum of intrinsic and extrinsic risk factors and the *interaction* between them promote the likelihood of an injury emerging [4]. Olsen et al. [5] reported that, in team handball, female players (sex as the intrinsic factor) are more prone to an anterior cruciate ligament (ACL) injury when playing on hard pitch surfaces (playing surface as the extrinsic factor) than male players (for a review see Alentorn-Geli et al. [6]). Based on this finding, studies have attempted to investigate how male and female players perform cutting actions, such as rapid changes of direction or jump landings, with the aim of determining which predictors of risk place the knee of female players in a vulnerable situation when shoe–floor friction is high [7].

To date, studies investigating situations leading to injuries have provided important information that has helped to develop a deeper understanding in sports medicine and injury prevention, leading to changes in the laws of the game and strict enforcement of the rules by referees, with the aim of ensuring player safety [8–10]. For example, in 2006, on the basis of past findings, the International Football Association Board gave referees the authority to severely sanction fouls that were recognised to be dangerous, issuing a red card for players who tackled from behind or used an intentional elbow to the head [11]. These findings were derived from notational analysis, which is a useful technique for operationalising a variety of issues in a range of sports [12–14] as researchers can repeatedly and objectively record and assess the frequency of injuries and incidents [8–10, 15–19]. For example, the Football Incident Analysis (FIA) was developed [20] and administered [15, 16] in order to describe playing situations that lead to injuries and high-risk incidents. Findings indicated that most injuries resulted from one-on-one player interactions when a tackling player approached an opponent from the side. In addition, during most events the (to be) injured player seemed to be unaware of the opponent challenging him/her for ball possession [15, 16, 20].

2 Current Research Limitations

The notational analysis studies described have tended to focus on operationally cataloguing playing situations that lead to injuries. A potential limitation is that these methods are often lacking two of Kipling's[1] servants, i.e. how and why do particular behaviours lead to injuries [21]. To address this limitation, we propose that an ecological dynamics framework could further understanding on the role of performer–environment interactions in sport injury aetiology, impacting on both prevention and the design of rehabilitation programmes [21–23]. We consider *how* an ecological dynamics approach could enhance current methodology by providing a theoretical rationale to explain how players (inter)act relative to the movement of other players and the ball prior to injury onset. An injury in team sports is the result of a complex interaction between internal and external risk factors [5]. Thus, it is necessary to develop an in-depth understanding of the different constraints that emerged across different timescales, leading to the emergence[2] of injuries during performer–environment interactions [24]. This approach contrasts with current top-down[3] approaches in which sport governing bodies currently aim to protect players by modifying laws of the game or allowing stricter enforcement by match officials.

In existing research, Arnason et al. [25] assessed the effectiveness of a video-based awareness programme on contact injuries in a randomised controlled trial. The researchers introduced a 15-min presentation with information on the risk of playing elite football, typical injuries, and their mechanisms. The players worked in groups while analysing video sequences to develop preventive strategies. During the season, team physical therapists recorded all acute injuries, while coaches recorded match and training exposure. Injury incidence was compared between groups and between previous seasons for teams receiving the intervention (experimental group) and for a control group. No significant differences were observed in injury incidence between the intervention and control groups. Furthermore, there were no differences between injury incidents in past seasons and annual injury incidence when

[1] Kipling servants in past studies include description of who (e.g. the player), what (e.g. the player's action), where (e.g. the pitch location) and when (e.g. the match time and/or match score line) injuries happened.

[2] Emergence of contact injury is understood as a process in which a stable dyadic system state without injury suddenly changes into a destabilised state with an injury to either or both of the competing players.

[3] Top-down approach refers to the assumption that predictive sets of responses acquired a priori will lead to a particular outcome (an injury) during actual playing conditions.

the intervention was employed. The researchers indicated that, even when the players appeared to interpret the main injury mechanism on video, such performance did not transfer onto the pitch [25]. Recent research [26] in the movement science literature indicates that video training in isolation may not facilitate sport performance, as perception-only video observations are unlikely to support players in developing the necessary links with action (information–movement couplings) that underpin skilled performance [27]. Moreover, research indicates that prior to the onset of non-contact injuries, a contact often occurs between a player and an opponent that, in turn, leads the injured player to produce a sudden change of movement [28]. Due to the likely changes that will occur in movement control following this initial contact, it is possible that a subsequent injury will be a (direct) consequence of changes in a player's ability to exploit the necessary information–movement couplings that support reduction of injury risk. As player–opponent interactions are important for understanding injury mechanisms in team sports, past studies that have failed to study such performance aspects prior to contact [2, 10, 15, 16, 29–31], and behaviours in non-contact [13, 28, 32] injuries, tend to provide limited understanding on the information–movement couplings that players exploit in order to reduce injury risk.

In sum, present methodologies aimed at alleviating injury risks in team sports tend to emphasize operational preventive measures that only engage players in an indirect manner. That is, players are required to adapt to the constraints of new laws, or learn to avoid injuries without the opportunity to 'actively' learn to exploit the most useful information sources for the reduction of injury risk. As we outline below, players need to be able to perceive which actions *afford* a higher injury risk so that they can regulate movements to avoid them.

3 Ecological Dynamics

In studies of complex systems in sport [33], an increasing number of researchers have drawn on an ecological dynamics approach as a theoretical explanation of the relationship between adaptive behaviours[4] and coordination between performers [23]. Ecological dynamics has its origins in ecological psychology and dynamical systems theory. Ecological psychology postulates that behaviour emerges as a function of interactions between an individual (i.e. an athlete) and his/her performance environment [34] (for other ecological psychology schools that were influenced by Lewin's 1951 seminal formula B = f(PE)[5], see Araújo and Davids [35]). The interactions of a player–environment system rely on a constant exchange of energy surrounding the players and objects in the environment (e.g. light energy reflected from other players, ball, and playing surface) [36]. According to Gibson [34], movement causes changes to energy flows, which provide specific information to players on the properties of the environment [36]. By acting in the environment, a player can perceive affordances (possibilities for action) that enable him or her to gain knowledge of the environment [36], following a circular causality between perception and action. Ecological psychology predicates that players can exploit information from the surrounding distribution of energy to specify action-relevant properties of the performance environment [36]. In essence, players with limited abilities to act on the environment will not only have fewer possibilities to change the structure of the environment, but will have less accuracy in their control of movement, which could enhance injury risk [37].

Drawing on the previous ACL example, excessive joint laxity, prevalent among female players [6], may provide proprioceptive information[6] that affords excessive knee valgus rotation. In this sense, the information perceived by the (to be) injured player in specific one-on-one game situations invites specific actions that may trigger the inciting event (i.e. adaptive behaviours leading to action). Therefore, the behaviour leading to a cutting movement may be analysed as a function of the player being exposed to injury and the spatio-temporal interactions $B = f(P_{\text{injured-player}} \times E_{\text{opponent-player}})$ that emerge under specific task and environmental constraints of playing on a particular pitch surface (e.g. natural grass vs. on artificial turf). Such an approach emphasises the need to consider which information source a performer became perceptually attuned to as an affordance that prevented emergence of excessive knee valgus rotation. This notion is based on the idea that performers learn how to exploit specific information sources in the performance environment to constrain inherent self-organization tendencies in forming functional *multi-joint movement synergies*[7] that prevent risky actions emerging (e.g. valgus knee rotation). This theoretical proposition emphasises the need to design training programmes that will allow players to perceive affordances that will invite behaviours leading to a reduced injury risk [38]. It is contrary to current schools of thought [7], which mandate

[4] Adaptive behaviour encompasses perception, decision making, and action functions.

[5] Where adaptive behaviour (B) is a function between the person (P) and his or her environment (E) interaction.

[6] Afferent signals that travel to the central nervous system (CNS) from mechano-receptors located in the joints, among other places.

[7] The CNS exploits self-organization in a movement system to form temporarily assembled muscle complexes based on specific information picked up by the performer.

an approach that investigates differences between how male and females perform cutting actions, in order to determine how extensive joint laxity places the female knee at risk of knee valgus rotation. Traditionally, an adopted behaviour leading to an inciting event is formally analysed to identify intrinsic and extrinsic risk factors $B = f(P_{gender} \times E_{floor\ surface})$. Arguably, such perspectives seek to gain insight about how therapeutic modalities (e.g. stability and proprioceptive training) might reduce the risk of a player to injury. Based on those interventions, a performer is assumed to acquire neuromuscular control a priori that will be triggered during actual playing conditions and there is little consideration about the process in which information guides *emergent behaviours* during performance. For example, neuromuscular training interventions designed to prevent ACL injuries aim at increasing the magnitude of stabilizing forces that are required to be generated to resist the destabilising load applied to the knee prior to ligament damage [39]. However, these training programs neglect to consider the process in which affordances may be perceived by the player for generating required movement synergies (i.e. the required resistant forces) for reducing the risk of ligament injury.

Past studies have demonstrated that patterns of movement coordination emerge through the self-organised, spatial–temporal interactions of players under specific task and environmental constraints [40–42]. In dynamical systems theory, self-organisation is a principle used to explain how order spontaneously emerges among different system components (e.g. between different players and between players and ball, for a review see McGarry et al. [43]). An ecological dynamics approach has revealed how interactions between team players and the ball are constrained by information sources in the performance environment. These coordination tendencies lead to the emergence of patterns of stable behaviours (i.e. movement coordination within and between players) and variable actions (i.e. changes in movement coordination within and between players). Transitions between states of system stability and variability can be described by studying order parameters (i.e. a collective variable that synthesizes the relevant coordinated parts of the team game system) [41]. For example, Araújo et al. [44] modelled an attacker–defender dyad system as an order parameter in rugby. This order parameter was computed as the angle connecting a vector between the players and the try line. The order parameter was based on the notion that an attacking player with the ball aims to de-stabilise the dyadic system formed with an immediate defender (defender positioned between the attacker and the try line) by attempting to move past an opponent, taking the most direct path to the try line for creating scoring opportunities. This order parameter may describe the dyadic system coordination tendencies. That is, a symmetry between sub-system components (player or opponent) may be indicated when either attacker or defender locomotes towards the other. A player's movement pattern may be maintained until a specific phase in which either player will attempt to de-stabilize the system, causing a symmetry break in the state of the system, where one of the players gains an advantage for achieving the task goal (e.g. passing a defender for scoring or preventing the attacker from doing so) [44]. Control parameters are variables that influence order parameters and drive the dynamic system through different states. Studies of order–control parameter interactions have identified how and why behaviours emerge in competing dyadic systems [41]. Past research has demonstrated that control parameters of interpersonal distance and relative velocity regulate a performer's actions, leading to different performance outcomes [42]. For example, in rugby union, results revealed specific threshold values for interpersonal distance of less than 4 m, coupled with an inter-personal velocity of at least $1\ m{\cdot}s^{-1}$, at which an attacker passes a defender [41]. Importantly, only below this inter-personal velocity did physical contact tend to emerge between attackers and defenders, likely increasing the risk of injury [41].

With reference to the dynamics of performer–environment interactions, contact injuries are proposed to emerge from symmetry-breaking processes during player–opponent–ball interactions [45]. For example, based on the model of Araújo et al. [44], it may be expected that, when a tackle is made by a defender, the contact that may emerge provides a greater risk of injury to one of the sub-system components (i.e. either the dribbling attacker or the defender who is making the tackle). A potential injury model may propose that, when contact emerges, with an unsuccessful tackle (i.e. attacker continues to dribble past the defender) the player susceptibility to injury will be lower. However, according to the existing model, when contact between an attacker and the defender emerges during a tackle situation and the ball is lost, there is a higher risk of injury (based on the higher forces typically involved in dispossessing an attacker). When an attacker dribbles past the defender, avoiding contact, the system may still be de-stabilised, but with a lower injury risk. The Araújo et al. [44] model may provide a testable framework for predicting levels of injury risk in football dyads since it may describe system symmetry (i.e. when the players were approaching) and symmetry-breaking (when physical contact emerged or when attacker passed a defender without any physical contact).

The ideas signify that the importance of studying the emergence of injuries in team sports are predicated on analysing spatio-temporal positional data[8] of players

[8] Currently only available in two-dimensional coordinates.

during interpersonal interactions that lead to high and low injury risk situations. A key research task is to identify order and control parameters (especially critical threshold values) that might lead a dyadic system towards a performance region where a player remains at low or high risk of injury. Once this empirical programme of work has been completed, practice and training environments in team sports can be designed to encapsulate specific information sources as affordances to which players need to become attuned in order to prevent a player in a competing dyadic system entering a phase transition and increasing the probability of injury emerging. An important aspect to consider here is that by converging on a specific threshold value of a key spatio–temporal variable, a player might become exposed to affordances that invite the emergence of specific actions. Identified control parameter values might explain how competing dyadic systems enter such dysfunctional states. Despite the need for more research on these compelling theoretical ideas, there is some available support in practical data on injury risk in high-performance team sports. For example, FIA findings evidence that the attention of an injured player is often predominantly directed to the ball prior to injury [15, 20]. From an ecological dynamics perspective, at specific threshold values of key performance parameters (e.g. for variables such as interpersonal distance and displacement velocity), the attention of an at-risk player should be educated to a spatio-temporal variable, such as time-to-contact information or tau to specify the time to contact of an oncoming opponent attempting to tackle [46]. With this in mind, there is a need to identify the spatio–temporal variables that result in functional and dysfunctional behaviours that are likely to increase injury risk.

Identification of control parameter thresholds can provide the informational basis for the emergence of actions to avoid contact injuries. In ecological dynamics, it is proposed that the *education of attention* of performers to those parameter thresholds[9] during practice sessions can improve the decision making of players to reduce injury risk. For example, during training in small-sided games, players can learn to pick up affordances that invite specific actions that achieve intended performance goals and minimise the possibility of players entering high-risk situations [42]. Hristovski et al. [47] showed that, during practice, the actions (punch selection) of boxers were constrained by the distances they stood from the bag. Either side of this critical region, behaviours were constrained to emerge in limited areas of the perceptual–motor workspace. These results indicate that players can learn to utilise information to adapt emerging behaviours and achieve task goals efficiently and effectively and avoid undue injury risk. However, at other regions of the performance workspace, players can be constrained to perform actions that may be more risky or conservative (with respect to achieving team performance goals), decreasing or enhancing their exposure to injury risk. Individuals can be influenced to adapt to specific performance regions by adhering to particular coach instructions, depending on the competitive needs of the team (as illustrated by the work of Cordovil et al. [48] on basketball dribbling). This interpretation of the dynamics of affordance perception during injury avoidance has received support from the work of Hristovski et al. [49], identifying how functional adaptability of action was constrained by perception of 'harmability' or injury risk.

4 Conclusion

In this position paper, we have considered an ecological dynamics approach for the study of emergent actions and injury prevention in team games. This approach emphasizes the need to explore how information–movement couplings regulate the emergence of affordances for preventing contact injuries during team game performance. There is a need for an extensive programme of empirical work to examine the feasibility of implementing an ecological dynamics perspective on emergence of injuries in team games. As a result, coaches and sports clinicians may be able to re-design affordances in team sports training programmes based on established analysis of values of variables identified as control parameters in dyadic system interactions. In addition, incorporating affordances into training may be implemented as part of player rehabilitation, in order to safely bring an individual back to full playing capacity with enhanced knowledge of the environment. Ecological dynamics may prove to be a pertinent approach for discovering why players are injured and how to prevent contact injuries from emerging in team sports.

Acknowledgments Louis Leventer would like to express a special thanks to Mr. Pini Sharon, the physiotherapist of Maccabi-Haifa CF. The authors have no conflicts of interest to declare that are directly relevant to the content of this article. No funding was received by the authors to assist them in the preparation of this article.

References

1. Bjørneboe J, Bahr R, Andersen T. Gradual increase in the risk of match injury in Norwegian male professional football: a 6-year prospective study. Scand J Med Sci Sports. 2012;24(1):189–96.
2. Bjørneboe J, Bahr R, Andersen TE. Video analysis of situations with a high-risk for injury in Norwegian male professional football; a comparison between 2000 and 2010. Br J Sports Med. 2014;48:774–8.

[9] It is likely that threshold values are individual for each dyad and may change within individuals during the playing season.

3. van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. Sports Med. 1992;14(2):82–99.
4. Meeuwisse WH, Tyreman H, Hagel B, Emery C. A dynamic model of etiology in sport injury: the recursive nature of risk and causation. Clin J Sport Med. 2007;17(3):215–9.
5. Olsen O, Myklebust G, Engebretsen L, Holme I, Bahr R. Relationship between floor type and risk of ACL injury in team handball. Scand J Med Sci Sports. 2003;13(5):299–304.
6. Alentorn-Geli E, Myer GD, Silvers HJ, et al. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 1: mechanisms of injury and underlying risk factors. Knee Surg Sports Traumatol Arthrosc. 2009;17(7):705–29.
7. Bahr R, Krosshaug T. Understanding injury mechanisms: a key component of preventing injuries in sport. Br J Sports Med. 2005;39(6):324–9.
8. Fuller C, Junge A, Dvorak J. An assessment of football referees' decisions in incidents leading to player injuries. Am J Sports Med. 2004;32(1 suppl):17S–22S.
9. Fuller C, Smith G, Junge A, Dvorak J. The influence of tackle parameters on the propensity for injury in international football. Am J Sports Med. 2004;32(1 suppl):43S–53S.
10. Tscholl P, O'Riordan D, Fuller C, Dvorak J, Junge A. Tackle mechanisms and match characteristics in women's elite football tournaments. Br J Sports Med. 2007;41(suppl 1):i15–9.
11. Fuller CW, Junge A, Dvorak J. Risk management: FIFA's approach for protecting the health of football players. Br J Sports Med. 2012;46(1):11–7.
12. Bere T, Flørenes TW, Krosshaug T, et al. Mechanisms of anterior cruciate ligament injury in World Cup alpine skiing a systematic video analysis of 20 cases. Am J Sports Med. 2011;39(7):1421–9.
13. Olsen O-E, Myklebust G, Engebretsen L, Bahr R. Injury mechanisms for anterior cruciate ligament injuries in team handball a systematic video analysis. Am J Sports Med. 2004;32(4):1002–12.
14. Whitham R. The impact of the tackle: shoulder injuries in a rugby union team. Br J Sports Med. 2013;47(17):A1134.
15. Andersen TE, Tenga A, Engebretsen L, Bahr R. Video analysis of injuries and incidents in Norwegian professional football. Br J Sports Med. 2004;38(5):626–31.
16. Arnason A, Tenga A, Engebretsen L, Bahr R. A Prospective video-based analysis of injury situations in elite male football football incident analysis. Am J Sports Med. 2004;32(6):1459–65.
17. Fuller C, Junge A, Dvorak J. A six year prospective study of the incidence and causes of head and neck injuries in international football. Br J Sports Med. 2005;39(suppl 1):i3–9.
18. Fuller C, Smith G, Junge A, Dvorak J. An assessment of player error as an injury causation factor in international football. Am J Sports Med. 2004;32(1 suppl):28S–35S.
19. Rahnama N, Reilly T, Lees A. Injury risk associated with playing actions during competitive soccer. Br J Sports Med. 2002;36(5):354–9.
20. Andersen TE, Larsen Ø, Tenga A, Engebretsen L, Bahr R. Football incident analysis: a new video based method to describe injury mechanisms in professional football. Br J Sports Med. 2003;37(3):226–32.
21. McGarry T. Applied and theoretical perspectives of performance analysis in sport: Scientific issues and challenges. Int J Perform Anal Sport. 2009;9(1):128–40.
22. Glazier PS. Game, set and match? Substantive issues and future directions in performance analysis. Sports Med. 2010;40(8):625–34.
23. Vilar L, Araújo D, Davids K, Button C. The role of ecological dynamics in analysing performance in team sports. Sports Med. 2012;42(1):1–10.
24. Verhagen EA, van Stralen MM, Van Mechelen W. Behaviour, the key factor for sports injury prevention. Sports Med. 2010;40(11):899–906.
25. Arnason A, Engebretsen L, Bahr R. No effect of a video-based awareness program on the rate of soccer injuries. Am J Sports Med. 2005;33(1):77–84.
26. Travassos B, Araújo D, Davids K, O'Hara K, Leitao J, Cortinhas A. Expertise effects on decision-making in sport are constrained by requisite response behaviours—a meta-analysis. Psychol Sport Exerc. 2013;14(2):211–9.
27. Dicks M, Button C, Davids K. Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. Atten Percept Psychophys. 2010;72(3):706–20.
28. Krosshaug T, Nakamae A, Boden BP, et al. Mechanisms of anterior cruciate ligament injury in basketball video analysis of 39 cases. Am J Sports Med. 2007;35(3):359–67.
29. Quarrie KL, Hopkins WG. Tackle injuries in professional rugby union. Am J Sports Med. 2008;36(9):1705–16.
30. Crichton J, Jones DR, Funk L. Mechanisms of traumatic shoulder injury in elite rugby players. Br J Sports Med. 2012:46(7):538–42
31. Longo UG, Huijsmans PE, Maffulli N, Denaro V, De Beer JF. Video analysis of the mechanisms of shoulder dislocation in four elite rugby players. J Orthop Sci. 2011;16(4):389–97.
32. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes a prospective study. Am J Sports Med. 2005;33(4):492–501.
33. Davids K, Hristovski R, Araújo D, Serre NB, Button C, Passos P. Complex systems in sport. Routledge; 2013.
34. Gibson JJ. The senses considered as perceptual systems. Boston: Houghton Mifflin; 1966.
35. Araújo D, Davids K. Ecological approaches to cognition and action in sport and exercise: ask not only what you do, but where you do it. Int J Sport Psychol. 2009;40(1):5.
36. Davids K, Button C, Araújo D, Renshaw I, Hristovski R. Movement models from sports provide representative task constraints for studying adaptive behavior in human movement systems. Adapt Behav. 2006;14(1):73–95.
37. Dicks M, Davids K, Araújo D. Ecological psychology and task representativeness: implications for the design of perceptual-motor training programmes in sport. The Routledge handbook of biomechanics and human movement science. 2008. p. 129–39.
38. Withagen R, de Poel HJ, Araújo D, Pepping G-J. Affordances can invite behavior: Reconsidering the relationship between affordances and agency. New Ideas Psychol. 2012;30(2):250–8.
39. Holm I, Fosdahl MA, Friis A, Risberg MA, Myklebust G, Steen H. Effect of neuromuscular training on proprioception, balance, muscle strength, and lower limb function in female team handball players. Clin J Sport Med. 2004;14(2):88–94.
40. Headrick J, Davids K, Renshaw I, Araújo D, Passos P, Fernandes O. Proximity-to-goal as a constraint on patterns of behaviour in attacker–defender dyads in team games. J Sports Sci. 2012;30(3):247–53.
41. Passos P, Araújo D, Davids K, Gouveia L, Milho J, Serpa S. Information-governing dynamics of attacker–defender interactions in youth rugby union. J Sports Sci. 2008;26(13):1421–9.
42. Passos P, Milho J, Fonseca S, Borges J, Araújo D, Davids K. Interpersonal distance regulates functional grouping tendencies of agents in team sports. J Mot Behav. 2011;43(2):155–63.
43. McGarry T, Anderson DI, Wallace SA, Hughes MD, Franks IM. Sport competition as a dynamical self-organizing system. J Sports Sci. 2002;20(10):771–81.
44. Araújo D, Diniz A, Passos P, Davids K. Decision making in social neurobiological systems modeled as transitions in dynamic pattern formation. Adapt Behav. 2014;22(1):21–30.

45. Araujo D, Davids K, Hristovski R. The ecological dynamics of decision making in sport. Psychol Sport Exerc. 2006;7(6): 653–76.
46. Travassos B, Duarte R, Vilar L, Davids K, Araújo D. Practice task design in team sports: representativeness enhanced by increasing opportunities for action. J Sports Sci. 2012;30(13): 1447–54.
47. Hristovski R, Davids K, Araújo D, Button C. How boxers decide to punch a target: emergent behaviour in nonlinear dynamical movement systems. J Sports Sci Med. 2006;5(CSSI):60.
48. Cordovil R, Araujo D, Davids K, et al. The influence of instructions and body-scaling as constraints on decision-making processes in team sports. Eur J Sports Sci. 2009;9(3):169–79.
49. Hristovski R, Davids KW, Araujo D. Information for regulating action in sport: metastability and emergence of tactical solutions under ecological constraints. In: Araujo D, Ripoll H, Raab M, editors. Perspectives on cognition and action in sport. Hauppauge: Nova Science Publishers; 2009. p. 43–57.

5 Discussion

The thesis aimed to explore and provide insight, mainly into the first and second steps of van Mechelen's sports injury prevention model. In study-1 and study-2, the magnitude and severity of the injury problem predisposing Bundesliga football players was outlined. External risk factors were analyzed using epidemiological tools to answer practical sports science-related questions. In study 3, a novel theoretical rationale which may enhance insight into van Mechelen's second step of injury prevention was developed. The main idea proposed in the opinion piece is that the inciting event leading to contact injury in-game situations in invasion game sports may be captured by analyzing movement coordination between opposing players and the ball.

5.1 Reliability of media based injury surveillance system

The first aim of this thesis is to verify the degree of reliability of transfremarkt.de. Reliability results in Study 1 indicated an almost perfect agreement in cross-validation and very high agreement between the two sources regarding the reliability of injury information. Care should be taken, however, since cross-validation with another media-based source of information as a reference does not equate to proper validation, which refers to a gold standard consisting of primary and directly observed and collected injury reports. Nevertheless, it can be affirmed from the results that most injuries from the secondary media sources used for comparison are included in transfermarkt.de. However, reliability was checked using the most recent injury data collected (data from 2014). It is plausible that more injuries in previous seasons (e.g. in 2008) will be missing due to lower internet usage in previous years. Reliability results in study-1 indicated that, if administered in prominent leagues, sport injury studies based on media surveillance systems are likely to include most moderate and severe injuries but are likely to underestimate injuries causing minimal (greater than 3 days) absence of football activities. This is mainly because journalists might be unaware of players not on the roster for a very short period of training or competition due to an injury. More severe injuries result from untreated, minor injuries [103].

In order to reliably cover the entire spectrum of injuries (including injuries of minimal severity), a media-based surveillance system should be integrated with other types of injury surveillance systems, ideally with medical records prospectively collected by team physicians or physiotherapists on club grounds [39, 115]. The overall impression from the analysis done in Study 1 is that implementation of a media-based injury surveillance system may be feasible in prominent leagues which receive an exceptionally high amount of attention from the mass media, such as the English Premier League, Italian Serie A, and Spanish La Liga. Moreover, extracting data from multiple sources will likely improve the reliability of a media-based injury surveillance system. For example, the Kicker magazine may also have an inventory of injuries Bundesliga players sustain [116]. However, since this data was unavailable, this media source could not be combined with transfermarkt.de data to analyse injury patterns and risk factors (in studies 1 and 2).

5.1.1 Perspectives of future media assessment

Developing algorithms to extract information from tabulated formats and open journalistic reports where injury information is embedded in the open text is a promising direction. This requires advanced programming expertise to tackle significant challenges in identifying and extracting relevant data. The first challenge is obtaining URL addresses of potential injury reports, as URLs from open journalistic reports often lack a consistent format. For example, the URL `www.transfermarkt.de/matija-nastasic/verletzungen/spieler/143559` has a consistent structure, which, once the player name and ID code are known (extracted separately beforehand), allows for scraping the entire injury data (Verletzungen) in transfermarkt.de, which appears in a tabulated form. URL data can theoretically be obtained from search engines. However, ethical considerations must be considered (e.g., scraping Google pages is currently against their policy), complicating the identification of relevant URL addresses. Once URL addresses are identified, code must be developed to identify injury information embedded in the open report. Text mining techniques are increasingly used to retrieve injury information from open text reports on the web [117]. These techniques involve algorithms that extract relevant data from unstructured text, such as news articles, blogs, and social media posts. Text mining can provide valuable insights into injury trends and patterns by identifying key phrases and patterns related to injuries. This approach is beneficial in sports injury research, where comprehensive data collection is often challenging. By leveraging text mining, researchers can access a broader range of data sources, improving the accuracy and reliability of injury surveillance systems. This method also allows for the analysis of contextual information, such as player sentiments and rehabilitation progress, which can enhance the understanding of injury mechanisms and recovery processes. Retrieving information from open text is challenging since relevant injury information can be formulated differently (differences in phrasing text). Key phrases typically used in injury data, such as injury diagnosis and related injury vocabulary, will likely facilitate information detection. Artificial intelligence (AI) techniques, similar to those developed for translating online text (a good example is the DeepL project, which uses AI methods for text translation purposes; source at `https://www.deepl.com/en/whydeepl`) may be promising directions for capturing this information once keywords are detected in open text records.

The use of multiple media sources is strongly recommended mainly because pieces of information from different (independent) reports can be triangulated in order to identify duplications in injuries (if the injury discussed in these reports belongs to a one, similar injury event or a separate injury event). Data from multiple sources is likely to increase the likelihood of obtaining complete and accurate injury information since missing data from one source can be available in another, different source. For example, the actual time during a match (e.g. minute 58) can be extracted because it appears in report Y but is missing in report X, reviewing a similar match event. This new information (e.g. the time during a match) can lead to identifying other appropriate URLs, producing, in turn, additional helpful information about the injury in question. This cyclic iterative process may repeat itself in a loop, which can increase insight into injuries and the reliability of information for research purposes. Machine learning algorithms (for example, based on regression analysis) can be constructive in predicting missing values in injury data extracted from media. For example, machine learning models can be trained to approximate the severity of an injury with high precision (probability) based on known contextual information such as injury type, locality, player positional role and time in the season the injury occurred. Contextual information related to how a player feels during an injury or how one copes with an injury may also be available in media reports and is of tremendous importance for research. Players in rehabilitation are likely to provide interviews and speak to the media. While in rehabilitation, injured players use social media to maintain regular dialogue with their supporters [41]. Information from these sources can shed light on essential aspects related to injury and rehabilitation. For example, helpful insight into players' psychological process during rehabilitation can be revealed, which otherwise may not be available based on a traditional injury surveillance system collected by the medical team unless the aim of collecting data is specifically designed around a particular study objective. Moreover, media-based data on injuries may help better estimate the return to play, as we frequently find medical data biased by a priori clinical estimates.

However, a media-based injury surveillance system has some limitations, which one must know. The risk of selection bias is likely to be pronounced. One example is reporting injuries from "star" teams, receiving more media attention, and underreporting injuries from "inferior" teams. Along the same lines, selection bias can occur from differences in the attraction of matches. Journalists will likely provide more detailed (or complete) reports in more "important" or attractive matches to the public. More "successful" teams, those that participate in advanced stages of Cup tournaments, are also likely to be exposed to notably greater media attention compared to teams with fewer appearances in these events, which may result in more identifiable and more precise reports of injuries within some teams compared to others. Furthermore, relying on an injury surveillance system based on mass media might not be feasible in a setting with low media exposure, typically found in football leagues of lower divisions (and regional leagues), women's and youth football.

5.2 Distinguishing between match and training injuries

In this thesis, a distinction between match and training injuries was implemented due to variations in load characteristics, which justify differentiating between the two. Most Bundesliga matches are played on Friday and Saturday. Therefore, a match injury was defined as an injury sustained by a player on the same day or the following day of a match in which he participated. Conversely, a training injury was defined as an injury occurring outside the time players were believed to be playing in a match.

In the study "Epidemiology of Football Injuries of the German Bundesliga: A Media-Based, Prospective Analysis over 7 Consecutive Seasons," [116] training injuries were defined as any physical complaint sustained by a player during a training session led by an official team coach, including warm-ups and cool-downs. The study categorized injuries as training injuries if they occurred during supervised training sessions, encompassing team and individual training sessions, as well as recovery sessions conducted by the clubs' coaches. However, the authors estimated the number of players in a typical training session and did not have exact training exposure data for each player in each session. Without records indicating that a player was training at the time of an injury, it is challenging to attribute it to a training injury with complete certainty. Journalistic reports may provide additional information about whether an injury occurred during training, which could be helpful in identifying if an injury indeed happened in training.

The results outlined show a completely different injury pattern between match and training injuries regarding positional role differences and variations during the season. It is challenging to attribute strains occurring in matches to match injuries. Indeed, loads on the musculoskeletal junction (and on the whole body) are in several levels of magnitude larger in matches than in training [104]. Nevertheless, symptoms of a strain during the later phase of a match, where the physiological load is usually high, are very likely to be attributed to an overuse injury, which players may drag for a considerable period until symptoms are unbearable for continuing playing [58, 122–124, 127]. If a player has more awareness of his *environment* and what the environment *affords* (which action possibilities) in a performance context, this is likely to be translated to better "control" of movement, which may reduce sudden high load forces placed on the tissue typically manifested in sharp and sudden changes of movement. Teaching players strategies for exploiting key parameters and informing them about the relationship between themselves and the environment may allow players time to "prepare" for a movement which is about to come. This "preparation" may allow their body time to adapt, distributing forces on other less affected body tissues.

Match injuries of a non-contact nature can also indicate to what extent overuse injuries are unresolved or persistent problems in a club. This is because a return-to-play criteria for discharging players from an injury is subjective. "Being able to participate in training and match without restriction/ limitation" is a very vague statement. Perhaps a better criterion is "Being able to participate in training and match without pain". This is because players reportedly play while sustaining pain symptoms, often delaying rehabilitation to the beginning of a preparatory phase of the season [58].

5.3 Discussion of epidemiological methods and their limitations

Sophisticated statistical methods are applied primarily because the subject matter is very complex, involving 1) different kinds of injuries, 2) the interaction of multiple risk factors simultaneously, and 3) individual differences in injury history. An injury is often treated as a unique case (independent property), which is inappropriate. An injury is never a single independent case. Methods that can account for the independence of injuries do exist. However, the main difficulty lies in translating those analyses from such complex tools to practical, pragmatic conclusions which practitioners can communicate in clinical practice. Practitioners need "simple" conclusions, and there is a gap between the complexities of the methods applied, their assumptions and limitations, and the clarity of the message such methods provide in clinical practice. In other words, the gap from research to practice remains large and would require extraordinary means to bridge it.

To explicate, the methodology of adjusting for several previous injuries a player endured (i.e. player injury history) involves, as mentioned earlier, a very sophisticated analysis. The main aim is to isolate the very pronounced re-injury effect, allowing for a more precise estimation of the risk factor of interest. However, this methodology suffers from considerable problems. The total number of injuries a player sustained in previous seasons is of little importance. Considering the player's absolute number of previous injuries, the type/locality of injuries a player sustained is wholly overlooked. For example, player A can carry three injuries in his injury history, comprising two muscle strains and one ligament sprain. In contrast, Player B may carry two ligament sprains and one contusion. The baseline characteristics for sustaining a muscle injury differ between the two players. Each player will likely have different baseline risks for developing a particular re-injury type/ locality. This is because each injury, even of the same type/ locality, is unique regarding tissue damage, the degree of functional loss, player adherence to rehabilitation, player copying skills, injury management adopted, etc. This questions the feasibility of using epidemiological methods for 1) providing information to sports medical practitioners for use in clinical practice And 2) exploring van Mechelen's 1st step of injury prevention, a fundamental milestone for the successful implementation of prevention measures.

In a perfect world, one needs to establish the estimated risk of previous injury specific for each re-injury type/locality/playing position/period of season, which makes interpretation of risk factors analysis very difficult from a statistical and clinical point of view.

5.4 Risk factors analysis

5.4.1 Players positional differences in injury-risk

Study 1 described injury characteristics related to the type, locality and severity of injury. An inferential analysis for approximating injury risk across different playing positions was implemented. Despite no significant incidence-rate difference in injury across outfield playing positions, when considering the injury severity together with the incidence rate (as implemented in the form of injury burden), one can identify significant differences in risk across different playing positions. Similarly, results indicated significant differences in players' unavailability to match across different playing positions. The unavailability of matches for specific positions might indicate a problem from a team perspective. Due to a shortage in occupying specific positions, managers might fill these positions with players who are relatively unfamiliar with the demands these positions require, predisposing them to further injury risk.

5.4.2 Effect of period of season on injury-risk

Study 2 investigated the effect of the period of season on injury risk. When one divides the season into periods that reflect a player's preparation, as opposed to calendar months, practical interpretation in terms of a load of training on injury risk can be approximated more precisely. We found that the risk of sustaining a match injury was significantly greater in the second half of the season compared to the first quarter. We also found that a player was significantly at a greater risk of sustaining an injury in the last quarter of the season than in the first and third quarters, respectively. Lastly, the risk of injury was significantly greater during the in-season than during the preparatory period (pre-season and winter break) match and for training injuries.

5.5 Analyzing situations leading to the emergence of contact injuries

Based on ideas from the ecological approach to direct perception pioneered by James Gibson, in study 3, it was proposed how epistemologically – specifically in situations involving contact between opposing players – player behaviour leading to an inciting event (the mechanism of injury) can be studied in a team sport. In short, the environment *affords* players possibilities for action. His orientation to the environment determines the player's movement pattern. An orientation that *affords* passing an opponent player injury-free versus being injured from a one-foot / slide-in tackle mechanism by an opponent player. Some of the *affordances* the environment provides in a specific contextual situation lead to desirable (adoptive) behaviour (such as scoring a goal or successfully passing the ball to a player), while others are injurious, leading to dysfunctional behaviour (i.e. contact injury). By analyzing player-opponent interaction in episodes of high-risk game situations, practitioners can gain insight into critical parameters players perceive as functional, leading to dysfunctional, injurious behaviour (the inciting event). For example, prior to a particular match situation, specific training sessions can be designed to help a player to attune to a particular value of relative velocity and inter-personal distance which a player might face during a coming match from an opponent he is likely to meet (guarding him on the pitch as both players fill similar positional roles). However, these threshold key values can only be captured once a player is being analyzed in relation to his environment (other players, the ball and even the referee). This relationship affords an outstanding, beautiful performance skill that leads to a goal, a high-risk incident, or even a contact injury.

Limb-tracking technology, which is currently being explored by FIFA, offers a range of possibilities for enhancing research on injuries in football [125, 126]. Some potential directions it can be beneficial includes:

1. **Detailed Movement Analysis:** Limb-tracking technology provides real-time, three-dimensional visual representations of players' movements. This allows researchers to analyze the biomechanics of players in great detail, identifying movement patterns that may contribute to injuries.

2. **Injury Mechanism Identification:** In line with the theory of Ecological Dynamics (see paper 3), by tracking the precise movements of players, researchers can better understand the mechanisms behind contact injuries. The data can be helpful to better understand which information players attune leading to a contact injury. Thus, it will help in understanding better risky movements or situations that are more likely to result in injuries.

3. **Preventive Measures:** With detailed data on player movements, coaches and medical staff can develop targeted training programs to correct potentially harm-

ful techniques and improve overall player safety (as indicated by the education of attention in paper 3).

4. **Rehabilitation Monitoring:** Limb-tracking can be used to monitor players' movements during rehabilitation, ensuring that they are performing exercises correctly and not putting themselves at risk of re-injury.

5. **Performance Optimization:** Understanding the relationship between movement patterns and injuries can also help in optimizing player performance. By minimizing injury risks, players can maintain higher levels of performance throughout the season.

6. **Data-Driven Decisions:** The technology provides a wealth of data that can be used to make informed decisions about player health and safety. This data can be integrated with other injury surveillance systems to provide a comprehensive view of player well-being.

5.6 Limitations

The studies suffer from limitations that are likely to influence results, hence the strength and confidence in which conclusions can be drawn. In study 1, data corresponding to the actual system (formation) a player filled during a game was unknown and, therefore, could not be considered when determining the role a player filled in a given match. To exemplify, depending on the line-up formation of a match, a player in a given position can fill different positional roles, which are likely to influence the injury characteristic. For example, an offensive midfield player may occupy the lateral side of the pitch or the central part, depending on whether the match line-up is 4-3-3 or 4-4-2. In addition, regarding the number and type of injuries sustained, player susceptibility to injury was not considered a covariate in regression analysis in studies one and two. Injury risk differences were obtained without equalizing players' injury history (some players were more susceptible to an injury due to a more extensive injury history than other players). Preferably, the first two seasons of participation (seasons 2008 and 2009) should only be used to establish a baseline of the player's injury history. The analysis should include only players who participated in at least three consecutive seasons, where the data for actual measurement of the dependent variable starts with the third consecutive season a player participated in. The total number of injuries for the past two consecutive seasons should be added as a covariate to establish baseline characteristics for each observation in the analysis. This way, it is possible to balance player injury history, estimating risk differences between groups after adjusting for previous injury confounders.

Therefore, because of the importance of previous injury confounding effects, studies investigating the effect of risk factors, at a minimum, should include players participating for at least three consecutive seasons (unless information on players' previous injuries is available). Data from only the third season onwards can be used for quantifying the underlying effect of interest, while injury data in terms of the total number of injuries and the total number of lay-off days from the first two seasons will be used for calculating players' previous injuries as a covariate. However, including only players who participated for at least three consecutive seasons in the cohort will make data requirements even more demanding in terms of the sample size needed. This approach may limit the generalizability of the findings due to the reduced sample size and potential selection bias. Despite these challenges, this methodology is crucial for accurately assessing the impact of risk factors on injury occurrence, as it accounts for the confounding effects of previous injuries and provides a more robust analysis of the underlying factors contributing to injury risk.

Furthermore, study-1 regression models did not implement correction for multiple comparisons (as done when adding a random intercept for each player who participated in multiple seasons).

5.7 Conclusion and Practical Implementation

1. **Study 1: Injury Patterns and Risk Differences Among Playing Positions – A Media-based analysis**
    a) **Conclusion:** The study provides information about the injury pattern based on a public register. This study also identified significant differences in injury patterns and risks among different playing positions in first-division Bundesliga football players. Certain positions may be more prone to specific types of injuries due to the demands and physical requirements of their roles on the field.
    b) **Practical Implementation:** The validation of media-based data opens up new research opportunities, allowing researchers to explore injury trends and risk factors across different leagues and levels of play. This can lead to more generalized findings and broader applications of injury prevention strategies. Coaches and medical staff can use this information to tailor training and injury prevention programs specific to each playing position. For example, defenders might need more focus on preventing lower limb injuries, while midfielders might benefit from exercises that enhance endurance and agility.
1. **Study 2: Risk Differences in Different Season Periods**
    a) **Conclusion:** The study found that injury risks vary throughout the football season, with certain periods posing higher risks than others. Factors such as match congestion, training intensity, and recovery time play a significant role in these variations.
    b) **Practical Implementation:** Teams can use these insights to adjust training loads and recovery strategies during high-risk periods. Implementing periodized training programs that account for peak injury times can help reduce the overall injury incidence.

1. **Study 3: Mechanisms Leading to Contact Injury in Team Sports**
   a) **Conclusion:** This study provided a theoretical framework for understanding how contact between opponent players can lead to injuries. It highlighted the importance of Ecological Psychology and Dynamical System Theory for understanding player interactions in the occurrence of contact injuries.
   b) **Practical Implementation:** The theory can inform the development of training drills that simulate match conditions and teach players how to safely engage in physical contact. Additionally, rule changes or enforcement strategies could be considered to minimize high-risk contact situations during matches.

Overall Practical Implementations:

1. **Injury Prevention Programs:** Develop position-specific and period-specific injury prevention programs based on the identified risk factors.
2. **Training Adjustments:** Modify training loads and recovery protocols during high-risk periods to minimize injury incidence.
3. **Player Education:** Educate players on safe techniques for physical contact and the importance of adhering to injury prevention strategies.
4. **Policy Development:** Use the findings to inform policy changes at the league or club level, aimed at reducing injury risks through better training practices and match regulations.

5.8 Final note

Recognizing the importance of studying injury patterns and investigating risk factors predisposing professional football players to injury, implementing a media-based injury surveillance system in prominent leagues is promising. If the techniques of extracting information from mass media are further developed, as outlined in previous sections, injury and exposure data can be utilized to explore practical sports science questions associated with injury risk.

With more sophisticated methods, results from epidemiological studies will have a much more clinical significance. The dissertation was meant as a contribution to this research process.

Bibliography

[1] C. FIFA. “FIFA Big Count 2006: 270 million people active in football”. In: *FIFA Communications Division, Information Services* 31 (2007), pp. 1–12.

[2] R. D. Hawkins and C. W. Fuller. “A prospective epidemiological study of injuries in four English professional football clubs.” In: *British journal of sports medicine* 33.3 (1999), pp. 196–203.

[3] M. Hägglund, M. Waldén, and J. Ekstrand. “Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons”. In: *British journal of sports medicine* 40.9 (2006), pp. 767–772.

[4] A. Nordström, P. Nordström, and J. Ekstrand. “Sports-related concussion increases the risk of subsequent injury by about 50% in elite male football players”. In: *British journal of sports medicine* 48.19 (2014), pp. 1447–1450.

[5] L. A. Toohey et al. “Is subsequent lower limb injury associated with previous injury? A systematic review and meta-analysis”. In: *British journal of sports medicine* 51.23 (2017), pp. 1670–1678.

[6] M. Arvinen-Barrow, D. Hurley, and M. C. Ruiz. “Transitioning out of professional sport: the psychosocial impact of career-ending injuries among elite Irish rugby football union players”. In: *Journal of Clinical Sport Psychology* 11.1 (2017), pp. 67–84.

[7] D. A. Kleiber and S. C. Brock. “The effect of career-ending injuries on the subsequent well-being of elite college athletes”. In: *Sociology of Sport Journal* 9.1 (1992), pp. 70–75.

[8] K. Moesch, C. Mayer, and A.-M. Elbe. “Reasons for Career Termination in Danish Elite Athletes: Investigating Gender Differences and the Time-point as Potential Correlates.” In: *Sport Science Review* 21 (2012).

[9] L. Ristolainen et al. "Sport injuries as the main cause of sport career termination among Finnish top-level athletes". In: *European Journal of Sport Science* 12.3 (2012), pp. 274–282.

[10] G. G. Arliani et al. "Professional football can be considered a healthy sport?" In: *Knee surgery, sports traumatology, arthroscopy* 24.12 (2016), pp. 3907–3911.

[11] G. G. Arliani et al. "Early osteoarthritis and reduced quality of life after retirement in former professional soccer players". In: *Clinics* 69 (2014), pp. 589–594.

[12] G. S. Fernandes et al. "Prevalence of knee pain, radiographic osteoarthritis and arthroplasty in retired professional footballers compared with men in the general population: a cross-sectional study". In: *British journal of sports medicine* 52.10 (2018), pp. 678–683.

[13] Z. Krajnc et al. "Increased risk of knee injuries and osteoarthritis in the non-dominant leg of former professional football players". In: *Wiener Klinische Wochenschrift* 122.2 (2010), pp. 40–43.

[14] M.-T. K. Kuijt et al. "Knee and ankle osteoarthritis in former elite soccer players: a systematic review of the recent literature". In: *Journal of science and medicine in sport* 15.6 (2012), pp. 480–487.

[15] M. Lohkamp, T. Kromer, and H. Schmitt. "Osteoarthritis and joint replacements of the lower limb and spine in ex-professional soccer players: A systematic review". In: *Scandinavian journal of medicine & science in sports* 27.10 (2017), pp. 1038–1049.

[16] S. R. Departmen. *Average matchday attendance of the Big Five soccer leagues in Europe from 2011/12 to 2021/22, by country*. 2022. URL: https://www.statista.com/statistics/261213/european-soccer-leagues-average-attendance/.

[17] DFL. *How did the Bundesliga compare with Europe's other top 5 leagues in 2021/22?* 2022. URL: https://www.bundesliga.com/en/bundesliga/news/comparison-europe-s-top-5-leagues-premier-league-la-liga-serie-a-ligue-1-18449.

[18] J. Ekstrand. *Keeping your top players on the pitch: the key to football medicine at a professional level*. 2013.

[19] D. Murphy, D. Connolly, and B. Beynnon. “Risk factors for lower extremity injury: a review of the literature”. In: *British journal of sports medicine* 37.1 (2003), pp. 13–29.

[20] J. Ekstrand. “Soccer injuries and their prevention (thesis)”. In: *Department of Surgery. Linköping, Sweden: Linköping University* (1982).

[21] E. A. Wikstrom, T. Hubbard-Turner, and P. O. McKeon. “Understanding and treating lateral ankle sprains and their consequences”. In: *Sports medicine* 43.6 (2013), pp. 385–393.

[22] W. Van Mechelen, H. Hlobil, and H. C. Kemper. “Incidence, severity, aetiology and prevention of sports injuries”. In: *Sports medicine* 14.2 (1992), pp. 82–99.

[23] M. Hägglund, M. Waldén, and J. Ekstrand. “Injury incidence and distribution in elite football—a prospective study of the Danish and the Swedish top divisions”. In: *Scandinavian journal of medicine & science in sports* 15.1 (2005), pp. 21–28.

[24] J. Bjørneboe, R. Bahr, and T. Andersen. “Gradual increase in the risk of match injury in N orwegian male professional football: A 6-year prospective study”. In: *Scandinavian Journal of Medicine & Science in Sports* 24.1 (2014), pp. 189–196.

[25] M. Hägglund, M. Waldén, and J. Ekstrand. “Injuries among male and female elite football players”. In: *Scandinavian journal of medicine & science in sports* 19.6 (2009), pp. 819–827.

[26] I. Jacobson and Y. Tegner. “Injuries among female football players–with special emphasis on regional differences”. In: *Advances in Physiotherapy* 8.2 (2006), pp. 66–74.

[27] M. Waldén et al. “Regional differences in injury incidence in E uropean professional football”. In: *Scandinavian journal of medicine & science in sports* 23.4 (2013), pp. 424–430.

[28] M. Mitrotasios et al. “The creation of goal scoring opportunities in professional soccer. tactical differences between spanish la liga, english premier league, german bundesliga and italian serie A”. In: *International Journal of Performance Analysis in Sport* 19.3 (2019), pp. 452–465.

[29] B. Clarsen, G. Myklebust, and R. Bahr. "Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire". In: *British journal of sports medicine* 47.8 (2013), pp. 495–502.

[30] W. van Mechelen. "Sports injury surveillance systems". In: *Sports medicine* 24.3 (1997), pp. 164–168.

[31] C. W. Fuller et al. "Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries". In: *Scandinavian journal of medicine & science in sports* 16.2 (2006), pp. 83–92.

[32] C. Finch. "A new framework for research leading to sports injury prevention". In: *Journal of science and medicine in sport* 9.1-2 (2006), pp. 3–9.

[33] C. A. Emery, W. H. Meeuwisse, and S. E. Hartmann. "Evaluation of risk factors for injury in adolescent soccer: implementation and validation of an injury surveillance system". In: *The American journal of sports medicine* 33.12 (2005), pp. 1882–1891.

[34] C. F. Finch. "An overview of some definitional issues for sports injury surveillance". In: *Sports medicine* 24.3 (1997), pp. 157–163.

[35] A. McManus. "Validation of an instrument for injury data collection in rugby union". In: *British Journal of Sports Medicine* 34.5 (2000), pp. 342–347.

[36] W. H. Meeuwisse and E. J. Love. "Development, implementation, and validation of the Canadian intercollegiate sport injury registry". In: *Clinical Journal of Sport Medicine* 8.3 (1998), pp. 164–177.

[37] M. Hägglund et al. "Methods for epidemiological study of injuries to professional football players: developing the UEFA model". In: *British journal of sports medicine* 39.6 (2005), pp. 340–346.

[38] J. Bjørneboe et al. "Injury surveillance in male professional football; is medical staff reporting complete and accurate?" In: *Scandinavian journal of medicine & science in sports* 21.5 (2011), pp. 713–720.

[39] C. L. Ekegren, B. J. Gabbe, and C. F. Finch. "Sports injury surveillance systems: a review of methods and data quality". In: *Sports medicine* 46.1 (2016), pp. 49–65.

[40] T. W. Flørenes et al. "Recording injuries among World Cup skiers and snowboarders: a methodological study". In: *Scandinavian journal of medicine & science in sports* 21.2 (2011), pp. 196–205.

[41] A. Nilstad, R. Bahr, and T. Andersen. "Text messaging as a new method for injury registration in sports: a methodological study in elite female football". In: *Scandinavian journal of medicine & science in sports* 24.1 (2014), pp. 243–249.

[42] M. Møller et al. "The SMS, phone, and medical examination sports injury surveillance system is a feasible and valid approach to measuring handball exposure, injury occurrence, and consequences in elite youth sport". In: *Scandinavian Journal of Medicine & Science in Sports* 28.4 (2018), pp. 1424–1434.

[43] L. M. Schwab et al. "Injury reporting via SMS text messaging and online survey in community sport: A feasibility study". In: *Translational Sports Medicine* 2.6 (2019), pp. 351–357.

[44] O. Faude et al. "Injuries in elite German football-A media-based analysis". In: *Deutsche Zeitschrift fur Sportmedizin* 60.6 (2009), pp. 139–144.

[45] L. Falese, P. Della Valle, and B. Federico. "Epidemiology of football (soccer) injuries in the 2012/2013 and 2013/2014 seasons of the Italian Serie A". In: *Research in sports medicine* 24.4 (2016), pp. 426–432.

[46] A. Grassi et al. "Epidemiology of anterior cruciate ligament injury in Italian first division soccer players". In: *Sports Health* 12.3 (2020), pp. 279–288.

[47] C. T. Nitta et al. "Epidemiology of anterior cruciate ligament injury in soccer players in the Brazilian championship". In: *Acta Ortopédica Brasileira* 29 (2021), pp. 45–48.

[48] A. Grassi et al. "Epidemiology of achilles tendon rupture in Italian first division football (soccer) players and their performance after return to play". In: *Clinical journal of sport medicine* 32.1 (2022), e90–e95.

[49] D. Niederer et al. "Return to play, performance, and career duration after anterior cruciate ligament rupture: a case–control study in the five biggest football nations in Europe". In: *Scandinavian journal of medicine & science in sports* 28.10 (2018), pp. 2226–2233.

[50] L. Leventer et al. "Injury patterns among elite football players: a media-based analysis over 6 seasons with emphasis on playing position". In: *International journal of sports medicine* 37.11 (2016), pp. 898–908.

[51] A. Grassi et al. “Eighty-two per cent of male professional football (soccer) players return to play at the previous level two seasons after Achilles tendon rupture treated with surgical repair”. In: *British journal of sports medicine* 54.8 (2020), pp. 480–486.

[52] O. Z. Lavoie-Gagne et al. “Return to Play and Player Performance After Meniscal Tear Among Elite-Level European Soccer Players: A Matched Cohort Analysis of Injuries From 2006 to 2016”. In: *Orthopaedic Journal of Sports Medicine* 10.1 (2022), p. 23259671211059541.

[53] O. Lavoie-Gagne et al. “Traumatic Leg Fractures in UEFA Football Athletes: A Matched-Cohort Analysis of Return to Play, Reinjury, Player Retention, and Performance Outcomes”. In: *Orthopaedic Journal of Sports Medicine* 9.9 (2021), p. 23259671211024218.

[54] B. Forsythe et al. “Return-to-play times and player performance after ACL reconstruction in Elite UEFA Professional Soccer Players: a matched-cohort analysis from 1999 to 2019”. In: *Orthopaedic journal of sports medicine* 9.5 (2021), p. 23259671211008892.

[55] A. Junge and J. Dvorak. “Influence of definition and data collection on the incidence of injuries in football”. In: *The American journal of sports medicine* 28.5_suppl (2000), pp. 40–46.

[56] F. R. Noyes, T. N. Lindenfeld, and M. T. Marshall. “What determines an athletic injury (definition)? Who determines an injury (occurrence)?” In: *The American journal of sports medicine* 16.1_suppl (1988), S–65.

[57] J. H. Brooks and C. W. Fuller. “The influence of methodological issues on the results and conclusions from epidemiological studies of sports injuries”. In: *Sports medicine* 36.6 (2006), pp. 459–472.

[58] R. Bahr. “No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports”. In: *British journal of sports medicine* 43.13 (2009), pp. 966–972.

[59] J. Ekstrand, M. Waldén, and M. Hägglund. “Hamstring injuries have increased by 4% annually in men’s professional football, since 2001: a 13-year longitudinal analysis of the UEFA Elite Club injury study”. In: *British journal of sports medicine* 50.12 (2016), pp. 731–737.

[60] C. Klein, T. Henke, and P. Platen. "Injuries in football (soccer)—a systematic review of epidemiology and aetiological aspects". In: *German Journal of Exercise and Sport Research* 48.3 (2018), pp. 309–322.

[61] W. van Mechelen. "The severity of sports injuries". In: *Sports medicine* 24.3 (1997), pp. 176–180.

[62] C. Fuller and S. Drawer. "The application of risk management in sport". In: *Sports medicine* 34.6 (2004), pp. 349–356.

[63] H. Morgenstern, D. G. Kleinbaum, and L. L. Kupper. "Measures of disease incidence used in epidemiologic research". In: *International Journal of Epidemiology* 9.1 (1980), pp. 97–104.

[64] M. C. Sheps. "On the person years concept in epidemiology and demography". In: *The Milbank Memorial Fund Quarterly* 44.1 (1966), pp. 69–91.

[65] N. Fitzharris et al. "The first prospective injury audit of League of Ireland footballers". In: *BMJ Open Sport & Exercise Medicine* 3.1 (2017), e000220.

[66] J. Larruskain et al. "A comparison of injuries in elite male and female football players: A five-season prospective study". In: *Scandinavian journal of medicine & science in sports* 28.1 (2018), pp. 237–245.

[67] J. H. Stubbe et al. "Injuries in professional male soccer players in the Netherlands: a prospective cohort study". In: *Journal of athletic training* 50.2 (2015), pp. 211–216.

[68] I. Shalaj et al. "Injuries in professional male football players in Kosovo: a descriptive epidemiological study". In: *BMC musculoskeletal disorders* 17.1 (2016), pp. 1–9.

[69] M. Hassabi et al. "Injury profile of a professional soccer team in the premier league of iran". In: *Asian Journal of Sports Medicine* 1.4 (2010), p. 201.

[70] J. Dvorak et al. "Injuries and illnesses of football players during the 2010 FIFA World Cup". In: *British journal of sports medicine* 45.8 (2011), pp. 626–630.

[71] J. Dvorak et al. "Medical report from the 2006 FIFA world cup Germany". In: *British journal of sports medicine* 41.9 (2007), pp. 578–581.

[72] A. Junge and J. Dvorak. "Injury surveillance in the world football tournaments 1998–2012". In: *British journal of sports medicine* 47.12 (2013), pp. 782–788.

[73] A. Junge and J. Dvořák. "Football injuries during the 2014 FIFA World Cup". In: *British Journal of Sports Medicine* 49.9 (2015), pp. 599–602.

[74] A. Junge, J. Dvorak, and T. Graf-Baumann. "Football injuries during the World Cup 2002". In: *The American journal of sports medicine* 32.1_suppl (2004), pp. 23–27.

[75] L. Engebretsen et al. "Sports injuries and illnesses during the London Summer Olympic Games 2012". In: *British journal of sports medicine* 47.7 (2013), pp. 407–414.

[76] A. Junge et al. "Sports injuries during the summer Olympic Games 2008". In: *The American journal of sports medicine* 37.11 (2009), pp. 2165–2172.

[77] A. Junge et al. "Injuries in team sport tournaments during the 2004 Olympic Games". In: *The American journal of sports medicine* 34.4 (2006), pp. 565–576.

[78] T. Soligard et al. "Sports injuries and illnesses in the Sochi 2014 Olympic Winter Games". In: *British journal of sports medicine* 49.7 (2015), pp. 441–447.

[79] J. Ekstrand et al. "Time before return to play for the most common injuries in professional football: a 16-year follow-up of the UEFA Elite Club Injury Study". In: *British journal of sports medicine* 54.7 (2020), pp. 421–426.

[80] G. Freckleton and T. Pizzari. "Risk factors for hamstring muscle strain injury in sport: a systematic review and meta-analysis". In: *British journal of sports medicine* 47.6 (2013), pp. 351–358.

[81] J. N. Salces et al. "An examination of injuries in Spanish professional soccer League". In: *J Sports Med Phys Fitness* 54.6 (2014), pp. 765–771.

[82] G. F. Reis et al. "Sports injuries profile of a first division Brazilian soccer team: a descriptive cohort study". In: *Brazilian journal of physical therapy* 19 (2015), pp. 390–397.

[83] H. Bayne et al. "Incidence of injury and illness in South African professional male soccer players: a prospective cohort study". In: (2018).

[84] E. Eliakim et al. "Pre-season fitness level and injury rate in professional soccer– a prospective study". In: *Sports Medicine International Open* 2.03 (2018), E84–E90.

[85] E. Smpokos et al. "Injury prevalence and risk factors in a Greek team's professional football (soccer) players: a three consecutive seasons survey". In: *Research in sports medicine* 27.4 (2019), pp. 439–451.

[86] A. Jones et al. "Epidemiology of injury in English professional football players: a cohort study". In: *Physical Therapy in Sport* 35 (2019), pp. 18–22.

[87] W. H. Meeuwisse et al. "A dynamic model of etiology in sport injury: the recursive nature of risk and causation". In: *Clinical Journal of Sport Medicine* 17.3 (2007), pp. 215–219.

[88] N. F. Bittencourt et al. "Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition—narrative review and new concept". In: *British journal of sports medicine* 50.21 (2016), pp. 1309–1314.

[89] C. Carling, E. Orhant, and F. LeGall. "Match injuries in professional soccer: inter-seasonal variation and effects of competition type, match congestion and positional role". In: *International journal of sports medicine* 31.04 (2010), pp. 271–276.

[90] M. Dauty and S. Collon. "Incidence of injuries in French professional soccer players". In: *International journal of sports medicine* 32.12 (2011), pp. 965–969.

[91] R. D. Hawkins and C. W. Fuller. "An examination of the frequency and severity of injuries and incidents at three levels of professional football." In: *British journal of sports medicine* 32.4 (1998), pp. 326–332.

[92] J. Ryynänen et al. "The effect of changes in the score on injury incidence during three FIFA World Cups". In: *British journal of sports medicine* 47.15 (2013), pp. 960–964.

[93] O. Faude et al. "Seasonal changes in stress indicators in high level football". In: *International journal of sports medicine* 32.04 (2011), pp. 259–265.

[94] L. Leventer, F. Eek, and M. Lames. "Intra-seasonal variation of injury patterns among German Bundesliga soccer players". In: *Journal of science and medicine in sport* 22.6 (2019), pp. 661–666.

[95] R. C. Team et al. "R: A language and environment for statistical computing". In: (2013).

[96] H. Wickham et al. "Welcome to the Tidyverse". In: *Journal of open source software* 4.43 (2019), p. 1686.

[97] H. Wickham. "rvest: Easily harvest (scrape) web pages". In: *R package version 0.3* 2 (2016), p. 2016.

[98] H. Wickham. *stringr: Simple, Consistent Wrappers for Common String Operations, R package*. 2017.

[99] G. Grolemund and H. Wickham. "Dates and times made easy with lubridate". In: *Journal of statistical software* 40 (2011), pp. 1–25.

[100] R. Berk and J. M. MacDonald. "Overdispersion and Poisson regression". In: *Journal of Quantitative Criminology* 24.3 (2008), pp. 269–284.

[101] W. Gardner, E. P. Mulvey, and E. C. Shaw. "Regression analyses of counts and rates: Poisson, overdispersed Poisson, and negative binomial models." In: *Psychological bulletin* 118.3 (1995), p. 392.

[102] D. B. Hall. "Zero-inflated Poisson and binomial regression with random effects: a case study". In: *Biometrics* 56.4 (2000), pp. 1030–1039.

[103] J. Ekstrand, J. Gillquist, and S.-O. Liljedahl. "Prevention of soccer injuries: supervision by doctor and physiotherapist". In: *The American Journal of Sports Medicine* 11.3 (1983), pp. 116–120.

[104] C. G. Brownstein et al. "Etiology and recovery of neuromuscular fatigue following competitive soccer match-play". In: *Frontiers in physiology* 8 (2017), p. 831.

[105] B. Nankervis et al. "How do professional Australian Football League (AFL) players utilise social media during periods of injury? A mixed methods analysis". In: *Journal of science and medicine in sport* 21.7 (2018), pp. 681–685.

[106] T. Horky. "No sports, no spectators–no media, no money? The importance of spectators and broadcasting for professional sports during COVID-19". In: *Soccer & Society* 22.1-2 (2021), pp. 96–102.

[107] L. Leventer et al. "Emergence of contact injuries in invasion team sports: an ecological dynamics rationale". In: *Sports medicine* 45 (2015), pp. 153–159.

[108] J. Ryynänen et al. "Combining data from injury surveillance and video analysis studies: an evaluation of three FIFA World Cups". In: *Global Journal of Medical Research* 14.3 (2014), pp. 1–9.

[109] L. Leventer, F. Eek, and M. Lames. "Inter-seasonal Dispositions of Injury-risk Among First Division Bundesliga Soccer Players". In: *Poster presented at the 5th World Congress in Science and Soccer.* 2017, p. 178.

[110] L. Leventer, F. Eek, and M. Lames. "Poster presentation 2017 Intra-seasonal Dispositions of Injury-risk Among First Division Bundesliga Soccer Players". In: *Poster presented in part of TUM academic year celebration*. 2017.

[111] L. Leventer, G. Schauberger, and M. Lames. "Poster presentation 2018 - Preseason preventive effect on in-season (Re) Injury-risk in German Bundesliga Football Players". In: *Poster presented in part of TUM academic year celebration*. 2018.

[112] L. Leventer, F. Eek, and M. Lames. "Injury patterns amoung elite football players: A media-based analysis of over siz seasons with emphasis playing position". In: *Book of Abstracts of the 21st Annual Congress of the European College of Sport Science Vienna Austria*. European College of Sport Science. 2016, p. 566.

[113] L. Leventer, F. Eek, and M. Lames. "Intra-seasonal Dispositions of Injury-risk Among First Division Bundesliga Soccer Players". In: *Book of Abstracts the 5th World Congress in Science and Soccer.* 2017, p. 320.

[114] L. Leventer. "Do we really need zero-inflated models in the analysis of injury-risk?" In: *Innovation und Technologie im Sport*. 2017, p. 124.

[115] D. Costello, E. Daly, and L. Ryan. "Sports Injury Surveillance Systems: A Scoping Review of Practice and Methodologies". In: *Journal of Functional Morphology and Kinesiology* 9.4 (2024), p. 177.

[116] K. Aus der Fünten et al. "Epidemiology of football injuries of the German Bundesliga: a media-based, prospective analysis over 7 consecutive seasons". In: *Sports Medicine-Open* 9.1 (2023), p. 20.

[117] V. Sarlis, G. Papageorgiou, and C. Tjortjis. "Sports Analytics and Text Mining NBA Data to Assess Recovery from Injuries and their Economic Impact". In: *Computers* 12.12 (2023), p. 261.

[118] R. Aicale, D. Tarantino, and N. Maffulli. "Overuse injuries in sport: a comprehensive overview". In: *Journal of orthopaedic surgery and research* 13 (2018), pp. 1–11.

[119] U. Tranaeus, S. Martin, and A. Ivarsson. "Psychosocial risk factors for overuse injuries in competitive athletes: a mixed-studies systematic review". In: *Sports Medicine* (2022), pp. 1–16.

[120] S. Martin et al. "Overuse injury and affects in competitive sport: A prospective longitudinal study". In: *Scandinavian Journal of Medicine & Science in Sports* 34.5 (2024), e14644.

[121] C. W. Fuller et al. "A framework for recording recurrences, reinjuries, and exacerbations in injury surveillance". In: *Clinical journal of sport medicine* 17.3 (2007), pp. 197–200.

[122] S. Verstappen et al. "The association between training load and injury risk in elite youth soccer players: a systematic review and best evidence synthesis". In: *Sports medicine-open* 7 (2021), pp. 1–14.

[123] V. Chang et al. "Football Analytics: Assessing the Correlation between Workload, Injury and Performance of Football Players in the English Premier League". In: *Applied Sciences* 14.16 (2024), p. 7217.

[124] H. Bengtsson et al. "Muscle injury rate in professional football is higher in matches played within 5 days since the previous match: a 14-year prospective study with more than 130 000 match observations". In: *British journal of sports medicine* 52.17 (2018), pp. 1116–1122.

[125] A. Steijlen et al. "Smart sensor tights: Movement tracking of the lower limbs in football". In: *Wearable Technologies* 2 (2021), e17.

[126] S. Parker, G. Duthie, and S. Robertson. "A framework for player movement analysis in team sports". In: *Frontiers in Sports and Active Living* 6 (2024), p. 1375513.

[127] F. M. Clemente et al. "Relationships between sleep, athletic and match performance, training load, and injuries: a systematic review of soccer players". In: *Healthcare*. Vol. 9. 7. MDPI. 2021, p. 808.

[128] W. Krutsch et al. "High return to competition rate following ACL injury–A 10-year media-based epidemiological injury study in men's professional football". In: *European journal of sport science* 20.5 (2020), pp. 682–690.

A Reprint permission from publishers

Thieme

Injury Patterns among Elite Football Players: A Media-based Analysis over 6 Seasons with Emphasis on Playing Position

Author: L. Leventer, F. Eek, S. Hofstetter, M. Lames
Publication: International Journal of Sports Medicine
Publisher: Georg Thieme Verlag KG
Date: Jul 28, 2016

Contact Publisher

Please review or edit your order if there is a need.

Sender	Comment	Attachment	Date & Time
Publisher Representative	Vielen Dank für Ihre Anfrage. Auch wenn Ihr Artikel nicht unter einer Gold Open Access-Lizenz veröffentlicht wurde, können Sie ihn trotz der Übertragung des Copyrights an Thieme sofort nach Erscheinen und gern auch in der publizierten Fassung (Version of Record) in Ihre kumulative Dissertation/Habilitation aufnehmen. Dies gilt für die Pflichtexemplare sowie für eine Veröffentlichung Ihrer Arbeit auf dem Hochschulserver und dem Server der Nationalbibliothek. Voraussetzung ist, dass diese Zweitveröffentlichung ausschließlich nicht-kommerziell erfolgt. Eine zusätzliche, ausdrückliche Lizenzgenehmigung durch den Verlag ist in diesem Fall nicht erforderlich. Thiemes Veröffentlichungsrichtlinien für AutorInnen finden Sie hier: https://www.thieme.com/en-us/journal-policies#9		Oct 14, 2024, 7:34:22 AM

CCC | RightsLink

LL

Intra-seasonal variation of injury patterns among German Bundesliga soccer players

Author: L. Leventer,F. Eek,M. Lames
Publication: Journal of Science and Medicine in Sport
Publisher: Elsevier
Date: June 2019

Journal Author Rights

Please note that, as the author of this Elsevier article, you retain the right to include it in a thesis or dissertation, provided it is not published commercially. Permission is not required, but please ensure that you reference the journal as the original source. For more information on this and on your other retained rights, please visit: https://www.elsevier.com/about/our-business/policies/copyright#Author-rights

BACK | CLOSE WINDOW

SPRINGER NATURE LICENSE
TERMS AND CONDITIONS

Nov 15, 2024

This Agreement between Louis Leventer Technical University of Munich ("You") and Springer Nature ("Springer Nature") consists of your license details and the terms and conditions provided by Springer Nature and Copyright Clearance Center.

License Number	5887170059417
License date	Oct 13, 2024
Licensed Content Publisher	Springer Nature
Licensed Content Publication	Sports Medicine
Licensed Content Title	Emergence of Contact Injuries in Invasion Team Sports: An Ecological Dynamics Rationale
Licensed Content Author	Louis Leventer et al
Licensed Content Date	Oct 7, 2014
Type of Use	Thesis/Dissertation
Requestor type	academic/university or research institute
Format	print and electronic
Portion	full article/chapter
Will you be translating?	no
Circulation/distribution	1 - 29