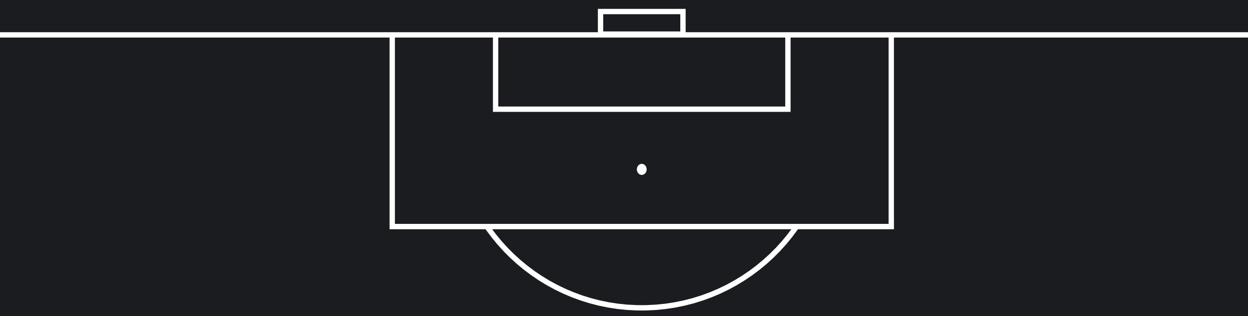

The influence of match events on injury incidence during male World Cup football

Epidemiological studies and video analysis of injuries

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“Without people, you're nothing.”

Joe Strummer

ABSTRACT

The aim of this thesis was to assess the effect of game-related match events on the variation in injury incidence in top-level male football. Specifically, the primary aims were to investigate: (1) a possible relationship between injury incidence and changes in the (goal) score, playing position and recovery time, (2) differences between foul play injuries and non-foul play injuries with regard to the match circumstances in which they occur, (3) the relationship between the number of fouls and injuries per match, as well as (4) a possible relationship between injury incidence and goals, injuries, as well as red and yellow cards. In addition, a secondary aim was to use video analysis of contact injuries to describe match circumstances in which contact injuries occur and to investigate possible independent predictors of contact injuries.

The material consisted of team physicians' post-match injury reports on 441 injuries (from men's FIFA World Cups in 2002, 2006 and 2010), FIFA's official match statistics from all matches and full video recordings of all matches. Data on the type and location, the time and the circumstances and consequences of injury were collected prospectively. From the match statistics, the time (minute) and number of goals, as well as red and yellow cards, were obtained, in order to calculate and compare the injury incidences during different match periods. Moreover, the total number of fouls per match was obtained in order to evaluate the association between the number of injuries and fouls. The full video recordings were reviewed and all identified contact injuries and contact injury risk incidents were analysed according to variables describing the match circumstances at the moment of injury.

These studies showed that the variation in injury incidence during a match was related to both changes in the score ($p=0.026$) and teams' drawing/losing/winning status ($p=0.008$), with players in winning teams running the highest risk of injury. There were also statistically significant differences in injury incidence between playing positions ($p<0.001$), with forwards having the highest injury incidence. A significant association between an increasing number of recovery days between matches and an increasing injury incidence was also found ($p=0.043$). Other findings were that the injury incidence increased within the five minutes following a goal, injury, or a red or yellow card ($p<0.001$) and that there was a correlation between the number of injuries and fouls in a match ($p<0.001$). The thesis also highlights some concerns relating to the widely applied video analysis methods.

In conclusion, these studies show that the injury incidence during a match in international football tournaments is affected to some degree by match events that are an essential part of football. Furthermore, these studies demonstrate that match statistics can be used succesfully in combination with injury report data in epidemiological research on football injuries.

Keywords: Epidemiology, Sporting injuries, Football

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SAMMANFATTNING PÅ SVENSKA

Skaderisken i internationell fotboll är hög. Flera studier har visat att skaderisken varierar under en match, men resultaten har inte varit samstämmiga, och det finns endast begränsad forskning avseende faktorer som påverkar skaderisken. Syftet med denna avhandling var att undersöka om vissa moment, som utgör en väsentlig del av fotboll som spel, som t.ex. ändringar i resultatet (ställningen), ojust spel ("fouls"), röda eller gula kort och skador, påverkar skaderisken under matchens gång, i internationell fotboll på högsta elitnivå. Ett ytterligare syfte var att analysera alla identifierbara skador och andra spelsituationer som statistiskt har en hög skaderisk med video-analys, för att identifiera spelsituationer, som eventuellt kunde förutsäga en ökad skaderisk.

Studierna byggde på skadestatistik (i form av rapporter, som lagläkarna fyllde i efter matcher) från samtliga matcher i VM-turneringarna 2002, 2006 och 2010 (sammanlagt 441 skador), på officiell match statistik från alla 192 spelade matcher under dessa tueneringar och på kompletta video-inspelningar från varje match.

De viktigaste fynden var att skaderisken varierade beroende på om laget var i ledningen målmässigt, låg under eller om det stod oavgjort (största risken hade spelare i lag som ledde). På samma sätt varierade skaderisken för spelarnas olika spelpositioner, där anfallare var mest utsatta för skador. Skaderisken var också större under en fem minuters period efter röda och gula kort, mål och skador, d.v.s. vid avbrott i matchen. Vi fann också ett positivt samband mellan antalet fouls och antalet skador per match, och mellan antalet skador per match och längden på speluppehållet mellan matcherna.

Slutsatsen är att skaderisken under en fotbollsmatch delvis beror på olika händelser i själva spelet; manga av dessa är dock oundvikliga. Spelare, tränare, lagläkare och de ledande organen inom fotbollen kan dra nytta av att kunna identifier matchperioder då skaderisken är stor, för att eventuellt kunna införa skadeförebyggane åtgärder. Dessa studier har också visat att match-statistik framgångsrikt kan användas för epidemiologisk forskning kring fotbollsskador. Huruvida dessa fynd kan tillämpas på andra nivåer inom fotbollen, förblir obesvarat. Framtida studier kommer att utvisa detta.

LIST OF PAPERS

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. The effect of changes in the score on injury incidence during three FIFA World Cups.
Ryynänen, J, Junge A, Dvorak J, Peterson L, Karlsson J, Börjesson M.
British Journal of Sports Medicine 2013; 47(15): 960–964.

II. Increased risk of injury following red and yellow cards, injuries and goals in FIFA World Cups.
Ryynänen, J, Dvorak J, Peterson L, Kautiainen H, Karlsson J, Junge A, Börjesson M.
British Journal of Sports Medicine 2013; 47(15): 970–973.

III. Foul play is associated with injury incidence: an epidemiological study of three FIFA World Cups (2002-2010).
Ryynänen, J, Junge A, Dvorak J, Peterson L, Kautiainen H, Karlsson J, Börjesson M.
British Journal of Sports Medicine 2013; 47(15): 986–991.

IV. Combining data from injury surveillance and video analysis studies: an evaluation of three FIFA World Cups™.
Ryynänen, J, Leventer L, Peterson L, Kautiainen H, Karlsson J, Börjesson M, Fuller CW.
Global Journal of Medical Research (H) 2014; 14(3): 1–9.

CONTENTS

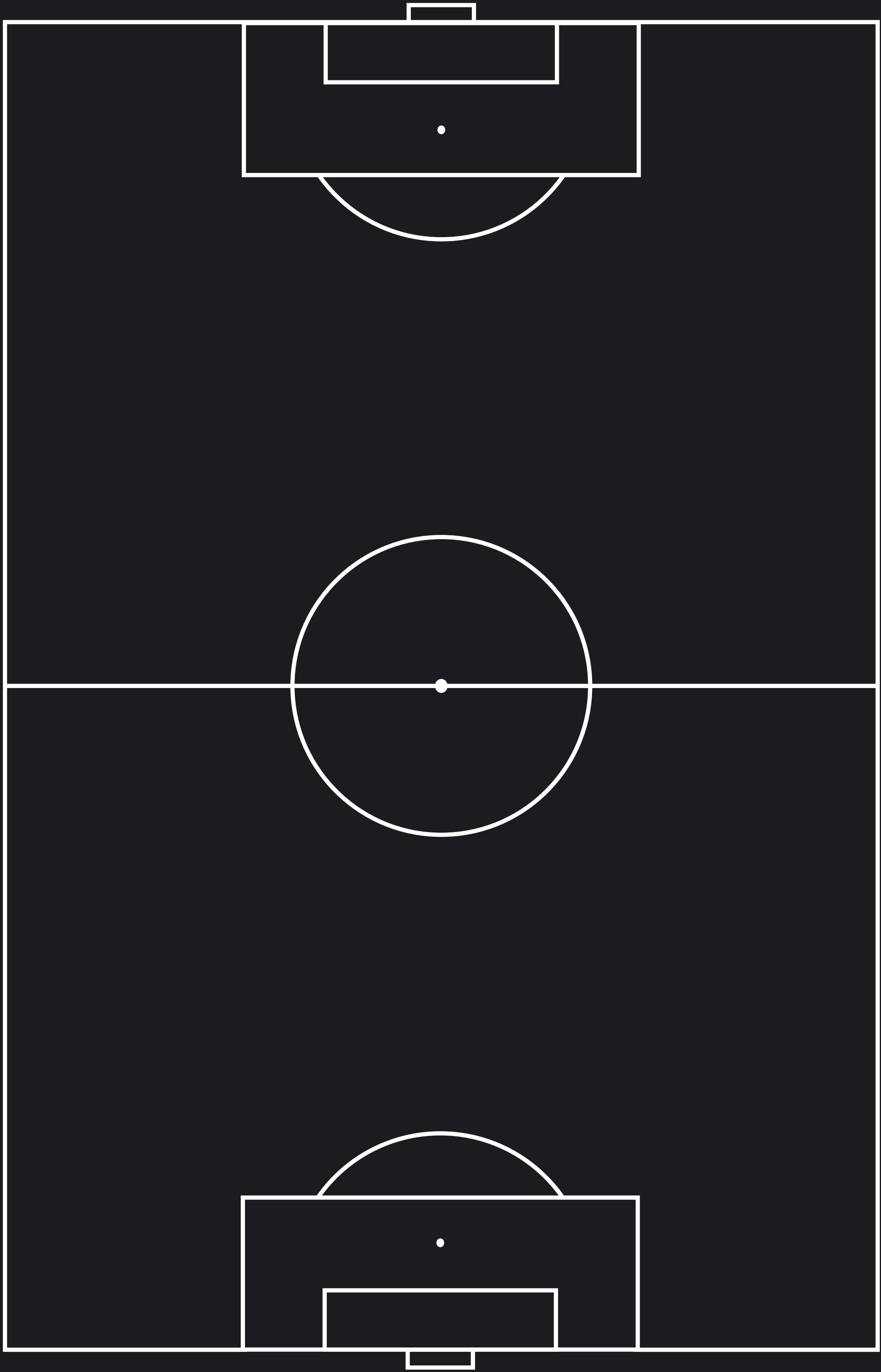
ABBREVIATIONS

ACL	Anterior Cruciate Ligament
AD	Anno Domini
CAF	Confederation of African Football
CEO	Chief Executive Officer
CI	Confidence Interval
COPD	Chronic Obstructive Pulmonary Disease
FA (English)	Football Association
FASA	White Football Association of South Africa
FIA	Football Incident Analysis
FIFA	Fédération Internationale de Football Association
FIFPro	Fédération Internationale des Associations de Footballeurs Professionnels
FLN	Algerian National Liberation Front
F-MARC	FIFA Medical Assessment and Research Centre
h	hour
IQR	Interquartile Range
IRR	Incidence Rate Ratio
Km	Kilometre
LCL	Lateral Collateral Ligament
MCL	Medial Collateral Ligament
min	minute
MRI	Magnetic Resonance Imaging
n	number
OR	Relative risk
OSTRC	Oslo Sports Trauma Research Center
PCL	Posterior Cruciate Ligament
PGDI	Potentially game-disruptive incident
ROM	Range Of Motion
SD	Standard Deviation
UEFA	Union of European Football Associations
US	Ultrasound
USD	United States Dollar
U-17 (age group)	under 17 years of age
U-19 (age group)	under 19 years of age

BRIEF DEFINITIONS

Contact injury	Injury resulting from player-to-player contact
Contact injury risk incident	An injury risk incident that results from player-to-player contact
Extra time	Additional match period played after the usual 45-minute halves during tournament knock-out stages, when the score at the end of second half is even
Extrinsic risk factor for injuries	Factor related to playing circumstances or environmental variables
Fair play	Playing by the rules, using common sense and respecting fellow players, referees, opponents and fans
Football	Association football or soccer
Foul	An infringement of the rules leading to a free kick or a penalty kick
Foul play injury	Injury in which the action causing the injury involved a violation of the laws (rules) of football
(Football) injury	Any physical complaint incurred during match play or training that received medical attention from the team medical team, regardless of the consequences with respect to absence from consequent match play or training
(Football) injury incidence	A value reflecting the risk of injury within a time frame, expressed as the number of injuries/1,000 player hours
Injury risk incident	Any situation in which the match was interrupted by the referee, or a player was on the ground for more than 15 seconds, or the player appeared to be in pain or received medical treatment

Injury severity	Expressed as the number of days of absence (lay-off time in days) from paricipation in football match play or training that results from an injury
Intrinsic risk factor for injuries	Factor related to the individual biological or psychological characteristics of a player
(Tournament) knock-out stage	Final stage of the tournament, after the group stage, in which losing teams are eliminated
Match exposure	Play between teams from different clubs
Overuse injury	Injury caused by repeated micro-trauma without a single, identifiable event responsible for the injury
Outfield playing position	All playing positions (defenders, midfielders and forwards) except goalkeepers
Playing formation	Reflects how players are positioned on the field and, in the present thesis, this is used to calculate match exposure for different playing positions
Potentially game-disruptive incident	A goal, injury or a red or yellow card
Re-injury	An injury occurring after an initial injury of the same type and location
Tackle	Any event, during the normal course of the match, that involves physical contact between two or more players, while one or more of the players are challenging for possession of the ball
Time-loss injury	An injury that causes absence (lay-off) from participation
Training exposure	Team-based and individual physical activities under the control or guidance of the team's coaching or fitness staff that are aimed at maintaining or improving players' football skills or physical condition
Traumatic injury	Injury resulting from a specific, identifiable event
EEG	Electroencephalography



INTRODUCTION

1

1.1 The history of football

1.1.1 The development of the modern form of the game

Almost 3,000 years ago, *Tsu' Chu* was played in China, in celebration of the Emperor's birthday.[1] The game was played with a stuffed leather ball using the feet, on very narrow fields, where the players tried to kick the ball into a goal made of a net fixed between bamboo poles.[1, 2] Centuries later, a similar game, *Kemari*, was developed in Japan. In *Kemari*, the players stood in a circle and passed the ball to each other, trying to avoid the ball touching the ground.[2] The first international pre-football was probably played in Kyoto, between Chinese and Japanese players, in 681 AD.[1] Different versions of pre-football were played in different cultures and on different occasions.[1] For example, in Egypt, an early form of football was played during fertility rites, while ancient Romans and Greeks played to prepare warriors for battle.[1]

Episkyros and *Harpastum* were other ancient forms of football originating from Greece and the Roman Empire respectively. These sports were more competitive variants of the game, where rough play was considered appropriate.[1, 2] In fact, Harpastum matches were often violent, involving serious injuries and killings.[1] The matches lasted for more than 50 minutes and the teams consisted of approximately 25 players.[1] In England, *Harpastum* had various interpretations, some of which involved kicking the skulls of defeated Roman soldiers or Vikings (during different time periods).[1]

In mediaeval Britain, another precursor form of today's football, called folk football, gained in popularity. Villages played against each other, with 500-a-side teams on fields up to 10 kilometres in length. The rules in this "mob football" were flexible: murder or manslaughter were practically the only actions regarded as fouls.[1, 3] This form of football was therefore considered violent and brutal and several monarchs attempted to ban people from playing football.[1, 3] Legal records imply that the prohibition never succeeded and, as a result, criminal trials were common.[3] Gradually, the game gained recognition. The village teams' players comprised both men and women, from all age groups and social classes.[3] One historical curiosity is the matches played between married and unmarried people, which could imply that some sort of fertility rituals were involved, or that it provided a forum for seeking a new life companion.[1, 3] Under the renaissance period, the more elaborate version, *Calcio*, which involved kicking, carrying and passing the ball over a line, was played in Italy.[1, 3] It was played on urban squares by young aristocratic men.[3]

As football in England remained popular despite attempts to ban it, it became a game played in schools. During the 19th century, public schools had to unify the rules of football in order to compete with one another.[1, 3] This was a crucial stage in the development for modern football, as it led to the separation between rugby and football (soccer) and the subsequent formation of the first governing body of modern football in 1863; the English Football Association (FA).[1-3] Football associations were then created in the same way in Scotland, Ireland and Wales and the modern game with its regulations then spread first around Europe, then to the rest of the world, leading to the establishment of FIFA in 1904.[1]

1.1.2 The history of the World Cup and how FIFA became a worldwide federation

Today, as a result of the gradual growth and expansion of the game, the world-governing body of football, FIFA, has six umbrella organisations, one on each continent, and 209 member associations.[4, 5] Until the 1930s, FIFA was dominated by European countries, with nearly three quarters of its members being European.[6] This was about to change: the success of South-American teams during the 1920s started to affect the way football was played in Europe and European clubs started to employ South-American players.[6] Many South-American countries were suffering from economic regression and football became a means of nation-building and international recognition.[6] Football was already not only a question of sport, it also had a political and social mission. The first FIFA World Cup in 1930 was held in Uruguay, but only four European teams were present, reflecting the tension caused by the fight for power between South America and Europe within FIFA. Consequently, Uruguay refused to participate in the 1934 and 1938 FIFA World Cups.[6] The tension between the continents started to decrease when the South-American Confederation obtained a permanent position on the FIFA Executive Committee.[6]

In South America, football was very popular and Buenos Aires alone had almost ten stadiums with a capacity of more than 40,000.[6] During World War II, the administrative operations in Europe were substantially reduced and membership of South-American associations gave FIFA important financial support. Subsequently, Spanish became one of FIFA's official languages in 1946, alongside English, French and German.[6]

In Africa, the contemporary form of football has strong roots in colonialism: the first football leagues and federations were set up in British, French and Belgian colonies.[6] Football was taught in elite schools and missionaries promoted football, as it was considered to have an important civilising and educating function.[7] Football started to gain wide popularity and top-level African (as well as South-American) players started to be transferred to European teams and were even encouraged to represent European national teams.[7, 8] Later, football was used as a political means in the de-colonialisation process.[6] The political links caused some controversy. During the 1920s, the nationalist and Muslim communities in Northern Africa started to create their own politicised clubs, such as the Algerian National Liberation Front (FLN) team.[6]

During the 1920s, football associations on other continents, which had until then been part of the British FA due to colonialism, started to obtain memberships of FIFA.[6] After the World Cup in 1934, qualification groups were formed, in order to ensure the participation of non-European teams in the World Cup.[6] For example, for the 1938 World Cup, a qualification group was created for Japan and the Dutch East Indies to ensure a place for Asia in the tournament.[6] FIFA was also actively seeking members from the Middle East and Central America: Costa Rica joined FIFA in the late 1920s, Lebanon and Syria joined in the mid-1930s, followed by El Salvador and Panama in the late 1930s.[6]

Continents wanted to maintain some of their power and autonomy and continental associations, such as the Union of European Football Associations (UEFA) and the Confederation of African Football (CAF), were created.[6] In 1974, the Brazilian, João Havelange, was elected as the first non-European president of FIFA, heavily supported by the African associations.[6] In 1976, the FASA (white Football Association of South Africa) was expelled from FIFA and the number of African and Asian representatives increased considerably for the 1982 World Cup.[6] FIFA has therefore grown, from being a federation dominated by Europeans, to a true global organisation supporting the local member associations.[6]

1.2 How football is played today and the physiological demands of top-level football

1.2.1 Basic regulations

An international football match is played between two teams of eleven players (ten outfield players and one goalkeeper), on a rectangular field 100-110 metres long and 64-75 metres wide.[9] The playing surface is green and can consist of either natural grass or artificial material that meets FIFA's requirements. The basic compulsory player equipment comprises a jersey, shorts, stockings, shinguards and footwear.[9] A match consists of two "halves" of 45 minutes, separated by a half-time period lasting a maximum of 15 minutes. The team scoring the larger number of goals by the end

of the match is the winner. If the match ends in a draw, the winner can be decided by the away-goals rule, extra time and/or penalty kicks. In the knock-out stages of FIFA World Cups, if the result remains a draw after 90 minutes and the minutes of additional time, two extra-time periods of 15 minutes are played, followed by penalty kicks if the result is still a draw after the two extra-time periods.[9]

Each match is controlled by a referee, with full authority to enforce the laws of the game, outlined by FIFA.[9] At professional level, the referee is usually accompanied by two assistant referees and a fourth official, all of whom assist the referee in applying the laws of the game. In official tournaments, a team can make up to three player substitutions during a match. The number of nominated substitute players is between three and 12, depending on the rules of the competition, but the maximum number of nominated substitutes in national "A" team matches is six.[9]

1.2.2 Physiological demands and important skills in football

Football (soccer) is a complex sport which requires muscular strength, power and endurance and which poses multifactorial demands on top-level players.[10, 11] In addition to excellence in playing skills and the cognitive ability to make quick decisions, it requires both aerobic and anaerobic power, good agility, adequate joint flexibility and the appropriate muscular development.[11] Players must also be capable of generating high torque during fast movements.[11] There appears to be a high level of heterogeneity in anthropometric and physiological characteristics among top-level players.[11] Importantly, the physical capacity of players influences both their technical and tactical performance, as well as their frequency of injuries.[10]

Top-level outfield players cover distances of 10-14 kilometres and goalkeepers up to four kilometres during a football match.[10, 12, 13] Players perform between 1,000-1,400 short activities during a match, changing the activity every four to six seconds.[10] These activities include sprinting, tackling, heading the ball, activities while in possession of the ball, passing the ball, changes of pace and sustained forceful contractions to maintain balance and control of the ball against pressure from opposing players.[10, 12] An analysis of the physical demands of English Premier League football divided player movements during a match into standing, walking, jogging, running, sprinting, skipping and shuffling, showing the wide variation in player movements, during which the short activities are performed, during a football match.[14] These authors defined movements made in possession of the ball, competing for the ball, evading opponents in order to become available to receive the ball, supporting team-mates in possession of the ball, as well as technical and tactical positioning movements, as the most purposeful movements during a match and concluded that the players performed these movements during a total of 41% of the match play on average.[14]

In general, professional football players cover longer distances than their non-professional counterparts.[10] Players performing at a high level therefore also tend to have a higher aerobic capacity than players at lower levels.[10] A study assessing the performance of German, French and Czech players from different age groups and skill levels showed that dribbling the ball at high speed was the ability that most discriminated between the groups, with adult top-level players performing this activity best.[51] Adult players were also superior to the other age and skill-level groups in power, speed and endurance.[15] Meeting the physical requirements of top-level football is, however, not enough. The results of a study analysing the characteristics of 105 elite youth players suggest that positioning and decision-making were the skills that best predict a performance level similar to that of adult players.[16]

Even if it is obvious that football players require a wide range of game-specific skills, such as ball control, dribbling and shooting the ball, cognitive and perceptual skills are also crucial to success.[17] A study of visual, perceptual and cognitive skills in young players from English Premier League Academies showed that the elite players had superior perceptual and cognitive skills, compared with the sub-elite players.[18] The authors suggested that these skills were important components of the game-reading ability.[18]

1.2.3 High-intensity activities, metabolism and fatigue during football matches

Common playing actions that involve high physical demands include sprinting (high-intensity running), tackling, heading the ball, passing the ball, changing the pace of running and sustaining forceful contractions to maintain balance and control of the ball.[10] Due to the long duration of the matches, the players are mainly dependent on aerobic metabolism, but there are match periods and playing situations involving high-intensity activity in which lactate accumulates and these short periods are often the most decisive for the match outcome.[10] In between these short high-intensity periods, in which lactate accumulates, players need periods of low-intensity activity to remove lactate from their working muscles.[10] In fact, top-level football appears to be characterised by five-minute intervals of high-intensity running, followed by five-minute intervals in which players run with significantly lower intensities.[12] An analysis of 360 goals at the highest level of German male football showed that straight sprinting was the most frequent action in goal-scoring situations, demonstrating the importance of short activities that require both power and speed, during the most decisive moments of a football match.[19] Accordingly, perhaps the most crucial ability for top-level football players is to be able repeatedly to perform high-intensity work.[12]

The average heart rates of players during football matches are 85% of maximum values on average and the peak heart rates are close to maximum.[20] The average oxygen uptake is estimated to be around 70-75% of the maximum values, although accurate measurements are difficult to perform.[20] In addition to post-match fatigue, players also experience temporary periods of fatigue during matches.[12, 20] The large number of high-intensity activities players have to perform during a match leads to elevated levels of lactate and acidosis and increased concentrations of blood glucose and free fatty acids.[20] Muscle glycogen is an important source of energy during football matches, but the muscle glycogen stores are not always depleted during a match.[20] Moreover, insulin levels decrease and catecholamine levels increase, indicating a high rate of lipolysis. The extent to which these changes in metabolic responses contribute to the development of fatigue still remains unclear.[20]

Outfield FA Premier League players cover approximately 1,800-3,100 metres of high-intensity running during matches.[21] In the Spanish La Liga, players perform approximately 17 bursts of very high intensity activity, resulting in an average distance of more than 300 metres covered at the highest intensity level during a match.[13] Possible differences between the findings in FA Premier League players' and La Liga players' performances may be explained in part by both different measurements and/or cultural differences. The amount of high-intensity running and sprinting also appears to be related to the success of the team.[22]. The periods of high-intensity running in the FA Premier League account for approximately 3% of the total match time, but the high-intensity periods are not evenly distributed and the time proportion of these activities can double during the most intense match periods.[23] Interestingly, the top five English Premier League teams have been shown to cover a significantly shorter distance of high-intensity running, compared with teams in the middle, or at the bottom of the table.[22] In accordance with this, a study following the physical performance of a succesful Italian Serie A team over three seasons suggested that a better understanding of player roles, tactics and team organisation could help to reduce energy expenditure during a match, helping the teams to maintain a high-level performance throughout the season.[24] However, another study showed that top-level players in an Italian Serie A and Champions League team performed significantly more high-intensity running and sprinting during matches compared with players in the top Danish league, who were thought to represent players of a relatively lower skill level.[12] A high level of heterogeneity in terms of the anthropometric and physiological characteristics among players in top teams has been reported.[11] There are, however, probably also cultural and/or regional differences in the physical and technical performances between different geographical regions, even at the top level. A study comparing these aspects between English Premier League and Spanish La Liga players showed that, on average, the English Premier League players covered a significantly longer distance in sprinting during matches, compared with Spanish La Liga players.[25] In the same way, South-American top-level players appear to cover significantly shorter total distances during matches, compared with FA Premier League players.[26] The underlying reasons for these cultural differences are unknown.

In addition to the temporary periods of fatigue during matches, the high physical demands of football also lead to post-match fatigue.[27] Post-match fatigue is associated with dehydration, muscle damage, glycogen depletion and mental fatigue. Intrinsic factors, such as the training status of the players, player age, gender and muscle fibre typology, are associated with the degree of fatigue that accumulates during a match.[27] In addition, extrinsic factors, such as match result, quality of opposition, playing surface and match venue, also appear to be associated with the development of fatigue.[27]

As the match and training schedules of top-level players are often congested, teams are forced to apply recovery strategies. Nutritional intake (milk drinks and meals containing high-glycaemic index carbohydrate and protein) after matches and cold water immersion have been used in recovery.[28] Importantly, sleep is an essential component of an efficient recovery process.[28] Other common recovery strategies include active recovery, stretching, compression garments, massage and electrical stimulation, although scientific evidence relating to the efficacy of these methods is yet to be presented.[28] Curiously, top-level Italian football players appear to cover both significantly longer total distances and distances made up of high-intensity running, during matches at the end of the season, compared with the start and the middle of the season.[12] This might suggest that players adapt to performing according to the increasing physical demands towards the end of the season. Or, alternatively, that players save themselves by reducing the running distances and the pace of running, in order to maintain an adequate performance level throughout the long season.

1.3 Health and social benefits of playing football

Although the present thesis focuses on injuries, it should be emphasised that football as a sport, and thus as a form of physical activity, also has important benefits. Regular physical activity has been shown to have positive effects on various, common and deleterious health issues, such as high blood pressure, obesity and stress, as well as tobacco, alcohol and drug abuse.[29, 30] Regular physical activity is also beneficial for preventing and/or treating various common diseases, such as cardiovascular diseases, depression, type 2 diabetes, osteoarthritis, chronic obstructive pulmonary disease (COPD) and cancer.[29-31, 33-36] Furthermore, regular physical exercise preserves physical and mental health and extends life expectancy.[29, 31, 32, 37] Beneficial effects of football, specifically on the psychological well-being of overweight boys,[38] on cardiac function,[39] on osteogenesis,[40] on hypertension[39, 41] and for type II diabetes patients,[42, 43] have been found. In addition, football appears to be useful in the rehabilitation of patients suffering from prostate cancer [44, 45] and for improving functional ability and aerobic fitness in elderly men.[46] As one of the most popular sports in the world, football therefore has an important mission in improving health. In further support of this, FIFA has used football-based campaigns for health promotion in children in South Africa, Zimbabwe and Mauritius,[47,48] showing that football may provide a framework for significantly improving health knowledge among children.

1.4 Consequences of football injuries and the importance of epidemiological research

Today, football is one of the most popular sports worldwide. In 2006, 265 million players and five million referees and officials were registered at FIFA,[49] reflecting the vast popularity of the game. However, playing football at top level entails a considerable risk of injury [50-55] and the consequences of injuries can be highly detrimental, for both teams and individual players. In view of the large number of football players, injuries are also a major problem for health care and society in general.

Studies of European male top-level football indicate that between 75-100% of the players in a team suffer football-related injuries and that a team of 25 players can expect an average of 50 injuries during the course of a season.[55, 56] An individual player suffers from a mean of 1.3-2.0 injuries per season, which results in 24-37 days of lay-off from training or playing football.[55, 57] There are limited data on the cost of injuries for a team, but, according to comments from the CEO (Chief Executive Officer) of a Ukrainian top-level club, the cost of having a first-team player injured for one month may be up to 500,000 euros (or approximately 687,000 USD).[58] Country-wide injury statistics, based on insurance company data, from Switzerland indicate that the annual cost of football injuries is around 130 million USD and that approximately half a million working days a year are lost due to football injuries.[59] Accordingly, the primary medical costs of football injuries have been estimated to be substantial [60].

The adverse consequences of football injuries are obviously not only reflected in high costs. A 11-year follow-up study of injuries in the UEFA Champions League showed that, on average, 14% of the players are unavailable to play matches, at any given time, due to injuries.[61] Perhaps unsurprisingly, another UEFA Champions League study showed that a low injury rate and high player availability were significantly associated with an improved team performance, both at domestic league level and at international European cup level,[62] reflecting the potential negative effects of injuries on teams' performances. Drawer and Fuller reported that, for almost half of all retired FA Premier League players, the reason for retirement was an injury.[63] Their data also indicated that almost a third of the retired players had diagnosed osteoarthritis in at least one of the joints of the lower extremities.[63] In fact, top-level football is associated with an increased risk of knee and hip arthrosis later in life.[63, 64] As a result, both the short- and long-term negative consequences of football injuries for individual players can be substantial.

Considering the popularity of football and the various unfavourable consequences of injuries, research on the epidemiology of football injuries, their treatment and their possible prevention is of great importance. In a four-step model for injury prevention

in sports, suggested by van Mechelen,[65] the preventive measures should be based on the knowledge of injury incidence and severity, as well as on the identification of the aetiology and mechanisms of injuries.

A great deal of epidemiological research has been conducted in order to identify risk factors for football injuries. This research has generally been based on insurance records, retrospective medical data, prospective injury surveillance, video analysis, or a combination of several methods.[53-57, 60, 61, 66-75] The different methodologies have often made direct comparisons of the results difficult, or even impossible. The need for further epidemiological research is also highlighted by several studies of injury-prevention strategies.[76-80] In order to make the results of different epidemiological studies of football injuries comparable, guidelines and consensus statements on the methods of choice have been proposed by both FIFA and UEFA.[75, 81] Consequently, most studies today apply these guidelines, making different studies in the field more comparable and complementary than before.

1.5 Incidence of injuries in top-level male football and risk factors for injuries

1.5.1 Injury incidence

Considering both player exposure to match play and training, the total injury incidence of "time-loss" injuries in top-level football male football is estimated to be 6-11/1,000 hours of exposure.[55, 56, 61, 82-85] During match play, the incidence of time-loss injuries is estimated at 23-32/1,000 hours of match play,[54-56, 61, 82-84] while the injury incidence during training is 1-6/1,000 hours and thus significantly lower than during match play.[52, 56, 61, 82-84, 86, 87] The fact that the total injury incidence is much closer to the injury incidence during training than during match play is most probably a result of the considerably higher player exposure during training, compared with the exposure during match play.

The reasons behind the significantly higher injury incidence during match play, compared with training, are probably multifactorial. While the most common injury locations, injury diagnoses and the severity of injuries appear to be similar during match play and training, traumatic or acute onset injuries constitute a higher proportion of the injuries during match play.[55-57] Accordingly, injuries caused by player-to-player contact (contact injuries) are significantly more common during match play than during training.[57] In contrast, muscular strains and ruptures are relatively more common during training, compared with match play.[57] One interesting finding from a study by Waldén et al.[82] was that European top-level football players, representing their national teams, had a tendency towards a lower injury incidence during training compared with their teammates, despite having higher match exposure. Although the tendency did not reach statistical significance (p=0.051),[82] speculative explanations for this tendency could be that injured players are often excluded from the national teams and/or that better players train with higher quality, as improving the quality of training has been shown to be an important aspect of injury prevention in football.[82, 88, 89] There could also, hypothetically, be genetic aspects that distinguish players that reach international level from other professional players. The study by Waldén et al. included data on 266 European top-level players, of whom 56% were exposed to national team play and the follow-up period was one season.[82]

1.5.2 Risk factors

The risk factors for football injuries are traditionally divided into intrinsic and extrinsic risk factors.[60] The intrinsic risk factors are related to the individual biological or psychological characteristics of the player, while the extrinsic risk factors are related to playing circumstances or environmental variables.[60] The present thesis focuses on the influence of game-related factors on injury incidence and accordingly on extrinsic risk factors for injuries.

Several intrinsic risk factors for football injuries have been identified and also studied, with some contradictory results. Perhaps the most important identified intrinsic risk factor for injuries is a previous injury,[60, 84, 90-92] highlighting the importance of the satisfactory rehabilitation of injuries during the lay-off period from match play. Other intrinsic risk factors that are being studied include player age,[60, 90, 93, 94] player race/origin,[93] joint stability,[60, 90, 91] functional asymmetries in the lower extremities,[95] body composition,[90] muscle strength [90, 92] and physical stress,[96] among many others.[60, 91, 97] Considering the large amount of research conducted in order to identify risk factors for football injuries, giving a detailed description of all the findings to date would not be meaningful from the perspective of the present thesis. However, it is important to acknowledge that the intrinsic and extrinsic risk factors are probably not independent of each other and can probably influence each other.[97] This may be particularly true for psychological risk factors. The psychological characteristics of a player are traditionally regarded as an intrinsic factor,[60] but changes in match conditions, which are regarded as extrinsic factors, may arguably affect the players' psychological state during a match. This is an important topic for the present thesis and it will be discussed in more detail below.

Extrinsic risk factors for injuries, or factors that relate to environmental variables and playing conditions, constitute the other large group of interest. Examples of extrinsic factors, and their association with injuries, that have been studied include foul play,[97] playing position,[60] field surface,[97-101] climatic factors,[97, 102-103] condensed match calendar,[90, 105, 106] contact between players/tackling [71] and match period (or time in the match),[50-52, 54-56] among others. From the perspective of the present thesis, the extrinsic risk factors of particular interest are playing position, different match periods, congested match calendar and foul play, all of which are studied in more detail in the present thesis.

1.6 Football-related injuries in other groups: women, youth football players, lower skill levels and referees

Although the present thesis focuses on top-level male football, epidemiological injury research in other groups is equally important and thus deserves a brief mention.

1.6.1 Injury characteristics in women's football

Junge and Dvorak conducted an injury-surveillance study of football injuries in world football tournaments between 1998-2012, which included data on male and female players, as well as players from different age groups.[54] Their results demonstrated that the overall injury incidences for male and female players were similar, with the exception of FIFA World Cups, where men had a significantly higher injury incidence.[54] In spite of this, differences in the circumstances of injury, as well as the injury diagnoses, between male and female players, have been demonstrated.[107] In particular, head injuries (particularly concussions) and injuries to the anterior cruciate ligament have attracted attention, as their incidences in women's football appear to be significantly higher than in male football.[54, 108-110] The extensive data from world football tournaments, obtained by Junge and Dvorak, demonstrated an increasing and alarming trend in the injury incidence among women in international top-level tournaments,[54] highlighting the need for preventive measures.

1.6.2 Differences between age groups

Although player age is a factor included in many epidemiological studies of football injuries and although it appears to be associated with the risk of injury, the results of previous research are, to some extent, contradictory in this respect. Waldén et al.[83] studied the injuries in European Championship football and found no statistically significant differences in the injury incidences between the U-19 European Championships (in 2005) and the adult European Championships (in 2004). On the contrary, Hägglund et al.[111] reported significantly higher injury incidences for adult male players in male European Championships, compared with male U-19 and U-17 European Championships (between 2006-2008). A prospective injury-surveillance study of English Youth Academy football players showed that the incidence at academy level is almost half that seen in adult professionals.[112] Chomiak et al. conducted a prospective study of factors related to severe injuries to football players of different age groups and skill levels.[91] The results indicated that the youngest players (14- to 16-year-olds) generally had less severe injuries than older players.[91] They also found further differences in the injury types and the locations of injury between different age groups; spinal problems were relatively more common complaints for players between 14-16 years of age than for other age groups, while 16- to 18-year-olds suffered relatively more joint sprains and fractures, compared with the other age groups.[91] One explanation for the relatively high frequency of spinal problems in young players may be that, with increasing age, football players become less mobile with regard to the rotation of the lumbar and thoracic portions of the spine.[113] The results of a study by Peterson et al.[114] indicated that players between 14-16 years of age are more prone to injuries than players between 16-18 years of age, perhaps suggesting an injury-preventive effect of skill development and improving physical performance. Logically, the anthropometric characteristics of players of different age groups are different,[113] which could also partly explain some of the differences in injury epidemiology when comparing youth players with adult players. A conclusion from a systematic review of strategies for the prevention of football injuries, with special emphasis on their applicability to youth players, was that more research should be conducted on the way strength training and conditioning should be adapted to youth players.[115] As a result, the epidemiology and prevention of injuries in youth players is another important area of future research.

1.6.3 Injuries at lower skill levels

Previous research on differences in injury incidence between different skill levels has also produced some contradictory results. Peterson et al.[114] conducted a prospective injury-surveillance study of football players of different age groups and skill levels. The authors found that players at a lower level (playing in third-division or amateur teams) had a higher incidence of severe injuries, compared with players at other levels.[114] Players at a lower skill level also had a tendency towards a relatively high proportion of overuse injuries.[114] On the contrary, in a study of Dutch amateur football players, the incidence of injury during training was 3.4/1,000 hours, compared with 21.9/1,000 hours during match play, figures similar to those reported for top-level players.[76] Accordingly, a study of Icelandic football showed no difference in injury incidence between the top division and the first division (the second highest level).[90] The results of a study comparing the characteristics of injured and uninjured football players showed that injured players described their ball dribbling and long-pass skills as poor more frequently than uninjured players.[97] Players with a high skill level have also been shown to have a shorter reaction time after a 12-minute run than uninjured players.[116] Accordingly, a longer reaction time after a 12-minute run has been shown to be more frequent in injured than uninjured football players,[97] presenting as a potential underlying factor for possible differences in the risk of injury between players at different skill levels. Moreover, playing football at an early age appears to be associated with a higher skill level later in life [116] and injured players appear to have a tendency towards having started to play football at a higher age, compared with uninjured players.[97] Early professional education might thus have a protective effect on injuries. Considering the total number of football players registered with FIFA (over 260 million) [49] and that more than 65,000 football players are registered as professionals in FIFPro,[117] it can be concluded that the vast majority of football players play at amateur levels. Future research should therefore also aim to investigate differences between the injury patterns at different levels of football and to assess the need for modified injury-prevention strategies at the different levels.

1.6.4 Referees should not be forgotten

The referees' mission is to supervise and ensure that the laws of the game are applied and they can therefore be regarded as performing a possible injury preventive role. In order to perform their duties at top level, football referees have to cover distances of 9-13 km during a match, a large percentage of which has to be covered by high-intensity running.[118, 119] As a result, referees have to be fit for considerable physical efforts and consequently also run a risk of suffering injuries. During the 2006 FIFA World Cup, 40% of the referees retrospectively reported having suffered an injury.[120] A study of Swiss referees, officiating at all levels of play, revealed injury incidences of 2.1/1,000 hours of match play and 0.1/1,000 hours of training.[121] Surprisingly, a prospective survey by Bizzini et al. of top-level referees, officiating at FIFA World Cup level, found that the injury incidence was as high as

20.8/1,000 hours,[120] approaching the injury incidence of top-level football players. For referees officiating at the top level, hamstring strains, calf strains and ankle sprains appear to be the most common injuries, while the most common locations of musculoskeletal complaints are the lower back, hamstrings, knees, Achilles tendons and calves.[120, 122] Clearly, there is a need for more epidemiological research on factors affecting the referees' risk of suffering injuries and for developing injury-preventive measures designed specifically for referees.

1.7 Player exposure and its association with injuries at top level

The consensus statement for epidemiological research on football injuries states that player exposure should be recorded and the injury incidence should be related to this exposure.[81] European top-level teams play an average of 61 matches a year and organise 240 training sessions.[61] Largely due to injuries, the availability (i.e. percentage of the players available for football activities) is lower than the full size of the squad, having been estimated at 77% for training and 86% for match play in a recent study of European top-level players.[61] Consequently, an individual European top-level football player may participate in an average of 34-36 matches and 162-175 training sessions, resulting in an average exposure of 254 hours (213 hours of training and 41 hours of match play) to football per season.[55, 105] A study by van Beijsterveldt et al.[76] of injury prevention in Dutch male amateur players recorded mean player exposure of 69 hours of training and 28 hours of match play, reflecting the considerable difference in exposure hours between the highest level and amateur level, especially in terms of the time spent in training.

Considering the substantial exposure time to football, especially at the top level, it is not surprising that a study including football players from different age groups and skill levels showed that more than a third of the players felt, at least occasionally, overloaded by the matches and training sessions and that only 20.4% of the players felt completely recovered before the next match.[116] However, there is considerable variation in the number of matches played (per season) between different European leagues and between the players within a team.[105] The top players of teams have a higher match exposure than other players, especially during the last ten weeks of a season, and players that participate in international tournaments have a higher match exposure than the players that do not.[105] Even though national team players have higher match-play exposure, they have not been found to run an increased overall risk of incurring an injury during the season. On the contrary, they appear to have a tendency towards a lower overall training injury incidence.[55, 105] Similarly, two studies by Carling et al.[123, 124] found no association between injury incidence and fixture congestion during professional European football. Interestingly, a study by Dellal et al.[125] of European professional football players showed that, although the total injury incidence was similar during congested and non-congested match fixtures, the training injury incidence was significantly lower during the congested periods, while the opposite was observed for match-play injury incidence. The authors discussed the potential effect of low-intensity exercise training on the lower training injury incidence during the congested periods.[125]

In fact, teams appear to reduce the training load during the congested periods.[126] Bengtsson et al.[106] studied muscle injuries in UEFA Champions League football during a 11-year follow-up period and found a significant association between fixture congestion and an increased muscle injury incidence. The results suggested that the congested calendar had little influence on team performance,[106] which is supported to some degree by a study by Mohr et al.,[12] which suggested that top-level players might adapt to increasing physical demands towards the end of the playing season, which corresponds to the period with a high match frequency.

However, a study focusing on players in 11 of the best European football teams found that 61% of the players with higher match exposure (more than one match per week) towards the end of the season either incurred an injury (29%) or underperformed (32%), suggesting that a congested match calendar could increase the risk of injury and lower performance during the following period.[105] Similarly, a study of injuries in Icelandic league football found that the match-play exposure was significantly higher for injured players, compared with uninjured players.[90]

1.8 Special characteristics of international (national team) football

The FIFA World Cup is played in the summer every four years, when the seasons of most domestic leagues are over. Each World Cup, since the 1998 FIFA World Cup in France, consists of 64 matches played by 32 participating teams and the tournament includes the preliminary group stage, as well as a knock-out stage, where the losing team is eliminated. The match schedule is intense and teams sometimes have only two full recovery days between matches.[127]

The FIFA injury-surveillance system, which has been implemented in FIFA tournaments since 1998 [54] and in which team physicians report injuries on post-match injury report forms, has defined an injury as any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or resulting time loss from football activities. The present thesis applies this definition, as the data are collected through this injury-surveillance system. Many other studies of European top-level football and English football have used a time-loss definition of injury.[55-57] Partly due to the different injury definitions, the injury incidence in FIFA tournaments has been substantially higher than in studies of European league football and/or UEFA Champions League football.[50-53] However, comparing the incidences of time-loss injuries only, between studies of FIFA World Cups and two studies of European Championship football, the injury incidence appears to be somewhat higher in FIFA tournaments (40.1-50.7/1,000 match hours vs. 20.5-41.6/1,000 match hours).[50-52, 83, 111] A comparison of the injury incidences between different international football tournaments, including female and youth football tournaments, also shows that the highest incidences are found in men's FIFA World Cups.[45]

Previous research also indicates that there are some differences in injury mechanisms between international (national teams) football tournaments and other levels of top-level football. The studies of English league football have shown that 38-41% of all injuries are caused by physical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contact between players,[56, 57] while the corresponding percentage in FIFA tournaments is between 73-86%.[50, 51, 54] It would appear logical that, partly due to this, contusion is by far the most common injury type in international football (accounting for 50-59% of all injuries).[50, 51, 54, 128] In UEFA Champions League football, muscle strain is the most common injury type, while contusions rank third on the list.[55] An 11-year follow-up of UEFA Champions League football, representing the highest level of European male football, found that the three most common injury locations were the hamstrings, adductor muscle group and ankles.[61] A 14-year follow-up from FIFA tournaments showed that the three most common injury locations in FIFA World Cups were the thighs, lower legs and ankles, while the hip/groin region was only the seventh most common injury location.[54] These differences might largely reflect the different injury definitions, as contusions may often not result in lay-offs from football and many of the injuries registered within the FIFA surveillance system will be excluded from any study applying a time-loss definition of injury. However, there may be additional, unknown factors that distinguish World Cup football from domestic league football, or tournaments within a specific confederation. The incidence of severe injuries in FIFA World Cups has been found to be surprisingly low compared with studies applying the follow-up of injuries.[54] This could reflect the fact that the severity of injuries is often underestimated in post-match medical evaluations of injured players, or that the risk of severe injuries in World Cup football is in fact lower. To date, no follow-up study of injury severity in World Cup football has been conducted.

The time trends in injury incidence for men's World Cup football during the past 14 years indicate that the injury incidence is decreasing.[54] In contrast, the total injury incidence in top-level European football has not decreased, although the incidence of ligament injuries is declining, probably as a result of injury surveillance and the application of preventive measures.[61] The time trends for injury incidence, separately for some common injuries, are described below.

1.9 Injury mechanisms and playing actions leading to injuries

Traumatic injuries constitute 76-94% of the injuries in match play.[55, 83, 118] Contact injuries are one subgroup of traumatic injuries. In full-season league football, player-to-player contact is involved in 38-62% of the injuries, while the same proportion in international top level tournaments (national team matches) is 63-86%.[50-52, 54, 56, 67, 83, 104, 118] Contact injuries constitute a significantly larger proportion of match-play injuries compared with training injuries.[57]

Tackling is an important playing action when it comes to the cause of contact injuries. A tackle generally refers to any event that occurs during the normal course of the match and involves physical contact between two or more players, while one or more of the players challenge for possession of the ball.[71, 73, 129-13] Match performance analyses of top-level football reveal that players tackle an average of 20 times during a match.[12] A study by Fuller et al.,[73] combining medical data (post-match injury reports filled in by team doctors) and video analyses of all tackle situations in international football tournaments, showed that approximately 2% of all tackles result in an injury and that the injury mostly (in 74% of the cases) affects

the player who is tackled. Studies applying video analysis have also identified characteristics of certain tackles that carry a high risk of injuries.[71, 132] Tackles with a direction from the side, tackles involving jumping vertically and/or tackles involving a clash of heads or two-footed tackles appear to involve a higher risk of injury than others.[71, 73] A high level of player error appears to be involved in the process of tackling, reflected by the frequent involvement of foul play in tackles, which is arguably mostly an undesirable tackle outcome for the tackling player.[73]

Common traumatic non-contact injury mechanisms are jumping or landing, turning or twisting, running and shooting [56, 57] and almost all muscle injuries occur as a result of non-contact mechanisms.[133] Non-contact injuries result in time-loss injuries more often than contact injuries and also involve longer estimated absences from playing football.[50] Non-contact injuries constitute a higher proportion of training injuries compared with match-play injuries.[56, 57] Overuse injuries are non-contact injuries that occur via non-traumatic mechanisms and account for approximately 8-28% of all injuries.[55, 56, 82]

1.10 Common injury types and locations

Between 73-87% of the injuries in football affect the lower extremities, with contusions, muscle strains and ligament sprains as the most common types and the thigh, knee, ankle, lower leg and hip/groin as the most common locations of these lower-extremity injuries, with slight differences in their relative proportions depending on the type of competition and/or injury definitions.[50-57, 82, 111]

In international football tournaments (national team matches), the most commonly affected body parts, following the lower extremities, are the head and neck (15% of all injuries), the trunk (8% of all injuries) and the upper extremities (7% of all injuries).[54]

1.10.1 Thigh injuries

Some 13-29% of all injuries in football affect the thigh [50-52, 55-57, 82, 90, 133] and thigh injuries constitute more than half of all muscle strains.[82, 133] The vast majority of thigh injuries are muscle strains of the hamstrings or the quadriceps muscle, where the posterior (hamstring) strains are up to twice as common as the anterior ones.[55, 56, 82, 90, 93, 133] Roughly half the injuries affect the biceps femoris muscle, the most common location, followed by the semitendinosus (16%) and semimembranosus (13%) muscles.[93] Contusions are also common, especially in World Cup tournaments.[50-52, 90, 93] Tendonitis can occur as well and it has been shown to account for 2% of all thigh injuries.[93] In several studies, hamstring injuries have been identified as the most common type of time-loss injury[55, 61, 83] and thus constitute perhaps the most challenging single group of injuries in football today.

The incidence of hamstring strains is between 2.4-4.1/1,000 hours of match play and 0.4-0.7/1,000 hours of train-

ing.[84, 90] Almost all (91%) hamstring injuries occur as a result of non-contact mechanisms, with running as the most common injury mechanism.[86, 90] Only a small minority of thigh injuries occur due to overuse.[90] As is the case with most injuries in football, thigh injuries have a higher incidence during match play than during training.[90, 93] During matches, their incidence has a tendency to increase towards the end of each half.[93]

Most thigh muscle strains are moderate or severe [81] and therefore cause a substantial injury burden for teams. A European top-level football club can expect an average of five to seven hamstring strains per season, leading to approximately 90 days and 15 matches missed.[55, 93] Previous research shows that 15-20% of all severe injuries affect the thigh and it also shows that hamstring strains are the most common severe injury type.[55, 82] Despite considerable efforts to prevent hamstring injuries,[134-136] an 11-year follow-up study of injuries in the UEFA Champions League showed no decreasing trend in muscle injury incidence.[61] Hamstring strains and other thigh muscle injuries therefore remain a problem to be solved in top-level football. Especially considering the common nature of these injuries and the substantial resulting lay-off times, epidemiological research and the subsequent development of effective prevention strategies are of great importance. As discussed further in this thesis, great efforts have been made to develop preventive measures for the most common types of football injury, with some highly encouraging results. For example, ankle

injuries display a decreasing time trend in European top-level football, most probably due to the emphasis on their prevention at clubs.[137]

In European elite football, the incidence of hamstring strains has been shown to be low during the preseason, after which it rises until it is two to three times higher during the competitive season (September to May) when all the high-intensity matches are played, with the injury peak observed in April.[55] Interestingly, the incidence of quadriceps strains did not vary substantially during the season.[55] However, another study of English elite footballers, by Woods et al.,[93] identified injury peaks in November and January.[93] It appears possible that many of the teams from the English study did not participate in Champions League matches and therefore had less match intensity during the spring and accordingly reported a different seasonal variation than in the study referred to above. The hamstring injuries that occur during training tend to peak in July and August.[93] In countries where the playing season has a different structure, for example, starting in the spring and ending in the autumn, the seasonal variation for thigh injuries is probably different.

The results of previous research, in terms of the risk factors, are somewhat contradictory. Fousekis et al.[95] did not find that a previous injury was a risk factor for a new hamstring injury, in contrast to Hägglund et al.,[84] who found a two to three times higher risk of hamstring injury during a season if the player had suffered a hamstring injury during the previous season. Árnason et al.[90] also identified previous hamstring strain as a significant risk factor for a recurring injury. A recurrence rate of 12% during the same season has been observed in English football.[93] Younger players have been shown to suffer significantly fewer hamstring injuries than older players, while players of black ethnic origin have been shown to suffer significantly more hamstring injuries than players of other ethnic origins.[90, 93] Woods et al.[93] suggested that a larger number of type II muscle fibres and an anteriorly tilted pelvis were possible underlying anatomical reasons for the higher risk observed in players with a black ethnic origin playing in English professional clubs. Goalkeepers have a significantly lower incidence of hamstring injuries than other playing positions,[93] probably because they run less during matches. Players with eccentric hamstring strength asymmetries and functional leg asymmetries have been shown to run a higher risk of hamstring strain compared with other players.[95] Moreover, a trend towards a higher percentage of body fat has been shown among players suffering hamstring injuries, compared with other players.[90] Leg dominance does not appear to affect the risk of hamstring strains, in contrast to quadriceps strains, which tend to affect the dominant leg of players.[55] A comparison of the incidence of hamstring strains across different divisions of English football reveals that the incidence is highest at the highest level,[93] perhaps due to a higher match and training intensity at the highest level, or possibly better quality of injury reporting.

1.10.2 Ankle injuries

Nine to nineteen per cent of all football injuries affect the ankle [50, 51, 54-57, 82, 83, 90, 111, 137, 138] and the incidence of ankle injuries is approximately 1-2.3 per 1,000 hours of match play and 0.2-0.4 per 1,000 hours of training.[90, 111, 137] There appears to be some seasonal variation in the incidence of ankle injuries, with almost half the ankle injuries during a season occurring in July, August and September – the first three months of the season (the cohort included English professional football players).[138] Ankle sprains have been found to decrease slightly during the past 11-year period in UEFA Champions League football.[137]

Most ankle injuries in football are ligament sprains,[50-52, 56, 57, 90, 138] which typically affect the lateral ligament complex, with the anterior talo-fibular ligament being the most commonly affected structure.[138] Up to 51% of all time-loss ankle injuries are lateral ligament sprains.[137] In accordance with this, Árnason et al.[90] found that lateral instability and a positive anterior drawer test are more frequently found among footballers with a previous history of ankle ligament sprain than among those without. Contusion is another common type of ankle injury, especially in international football.[52, 53, 132] Other types of ankle injury are fractures and overuse injuries, such as tendonitis, paratendonitis and inflammatory synovitis.[137, 138] Syndesmotic sprains and ankle impingement are uncommon types of time-loss ankle injuries.[137]

Contact between players during match play is the most common cause of ankle injuries, with tackling or being tackled as the most common injury mechanisms.[57, 132, 138] Up to 40% of ankle sprains have been found to be caused by foul play.[137] However, goalkeepers are an exception, as most of their ankle sprains appear to occur via non-contact mechanisms.[138] Common non-contact mechanisms for ankle injuries in football are landing, twisting and turning and – for goalkeepers – diving.[138] The direction of tackles causing ankle injuries is usually from the side, with a medial or lateral direction of force.[132] Approximately 11% of all time-loss ankle injuries are re-injuries.[137] Video analysis of ankle injuries in football has shown that the position of the ankle at the moment of injury is typically pronated, if the ankle is weight-bearing, and plantar flexed, if the ankle is non-weight-bearing.[132] The rotational axis of the ankle at the moment of injury is typically external or in eversion.[132] A previous ankle injury has been shown to be a significant risk factor for a new ankle injury in football.[90] Supporting this finding to some degree, Woods et al.[138] found that 32% of football players who suffered an ankle injury wore some kind of external support, such as taping or joint support, at the moment of injury, perhaps suggesting that they had suffered a previous ankle sprain. In addition, Hawkins et al.[56] found that the recurrence rate for ankle injuries was higher than the average recurrence rate for other injuries. However, Hägglund et al.[84] did not identify an ankle sprain during a season as a risk factor for an ankle sprain the following season in Swedish top-level league football. Waldén et al.[137] found that the vast majority of ankle sprains occurred in the dominant limb, while some other researchers have found that leg dominance does not appear to affect the occurrence of ankle injuries.[138]

1.10.3 Knee injuries

Between 7-20% of all injuries in football affect the knee [50-52, 55-57, 82, 84, 90] and the incidence of knee injuries resulting in time loss is approximately 2.3/1,000 hours in match play and 0.2-0.5/1,000 hours in training.[84, 90] The cause of knee injuries is usually traumatic and, as with most injuries, they are more common during match play than training.[90] However, overuse injuries of the knee also occur; for example, patellar tendinopathy appears to be a relatively common injury among elite footballers.[82, 90]

Most knee injuries are ligament sprains, contusions and ligament ruptures.[50, 51, 54, 56, 82, 90] The ligament sprains of the knee are mostly moderate to severe.[90] The most commonly affected structure is the MCL (53-76% of the knee ligament sprains), but also ACL, PCL, LCL injuries and meniscal tears occur.[55-57. 82, 90, 91, 139] Lundblad et al.[139] found that MCL injuries constituted more than 4% of the total time-loss injuries in UEFA Champions League football during a 11-year follow-up period and that nearly 70% of time-loss MCL injuries were caused by contact mechanisms. Foul play was involved in 24% of the match-related MCL injuries.[139] The study by Lundblad et al.[139] also showed that the rate of MCL injuries during the past 11 years is declining.

Even though the knee is not the most common location of injury, its injuries constitute a large proportion (30-34%) of the more severe injuries.[53, 55, 82, 90, 91, 114] Approximately a quarter of all time-loss knee injuries are severe.[55]

Previous knee injury is an important risk factor for a new knee injury [84, 90, 91] and instability of the knee joint appears to be more frequent among players who have suffered previous knee ligament sprains.[90, 91]

1.10.4 Hip and groin injuries

Studies in European elite football indicate that injuries to the hip and groin region constitute 12-16% of all injuries.[55-57, 82, 90, 94] The 11-year follow-up UEFA Champions League study found that adductor injury was the second most common injury, constituting 12% of all time-loss injuries.[61] In male World Cup football, injuries to the hip and groin constitute a much smaller percentage (5-6%) of all injuries,[50-52] probably explained by the large proportion of contusions in these tournaments.[50-52] Their incidence is between 3.7-4.0/1,000 hours of match play and 0.1-0.8/1,000 hours of training.[84] In contrast to most injuries affecting other parts of the body, the vast majority (73%) of hip and groin injuries result from overuse and only fewer than a third are traumatic.[94] Hip and groin injuries usually affect the muscles, with the adductors being by far the most commonly affected group (64%), followed by hip flexors/iliopsoas muscles (8%).[94] Adductor injuries are mostly adductor pain or muscle strains, which constitute 9% of all injuries.[55, 90] The incidence of muscle strains to the groin is approximately 2.7/1,000 hours of match play and 0.2/1,000 hours of training.[90] Up to 21% of all muscle strains have been shown to affect the hip and groin[82] and adductor-related groin pain is one of the most common types of overuse injury.[82] Importantly, hip and groin injuries constitute a heterogeneous group; a study of European elite footballers found 18 different diagnoses for hip and groin injuries over a study period of seven consecutive seasons.[94] Unspecified groin pain accounts for approximately 5% of the hip and groin injury diagnoses,[94] perhaps reflecting the challenging nature of the diagnostics for this region. Supporting this, US (ultrasound) and MRI (magnetic resonance imaging) are commonly used in the diagnostic evaluation of these injuries.[94] Femoro-acetabular impingement and labral tears have recently attracted more attention and they may have been underestimated in some previous studies.[94]

The mean lay-off resulting from hip and groin injuries is 15 days.[94] More than half the injuries are moderate or severe (result in lay-offs longer than eight days)[94] and about 12% are severe (result in lay-offs of over 28 days).[55] Hip and groin injuries thus constitute approximately 9-10% of all severe injuries.[55] Fifteen per cent of hip and groin injuries are re-injuries and re-injuries result in significantly longer lay-off periods than the initial injuries (23 vs. 14 days, on average).[94]

A previous injury is an important risk factor for a new injury.[84, 90] Other possible risk factors are higher age and a higher percentage of body fat.[90] However, another study showed no significant variation in the incidence of hip and groin injuries over different age groups.[94] Árnason et al.[90] found that players who suffered groin injuries also had a tendency towards a lower hip ROM (range of motion) and higher maximum average muscle power in the extension stage of a squat exercise, compared with non-injured players.

A UEFA injury study showed that the incidence of hip and groin injuries remained constant over a period of seven consecutive seasons.[94] However, there was variation in the incidence within the season, with March, followed by October and November, as the month in which the injuries peaked.[94] May was the month with the fewest hip and groin injuries, perhaps reflecting the lower match-play intensity during this month.[94]

1.10.5 Lower leg injuries

The lower leg is the most commonly injured body part in men's World Cup football and it is affected in 21% of all injuries.[54] Most injuries to the lower leg are contusions and they tend to be less severe than most other injuries.[90] Overuse injuries to the lower leg also occur.[90] A study by Fuller et al.[71] of tackles in international football found that the lower leg was the most commonly affected body part in injuries resulting from tackles. The 11-year follow-up study of injuries in UEFA Champions League football found that calf muscle injuries were the fifth most common type of time-loss injuries, preceded by hamstring injuries, adductor injuries, lateral ankle sprains and quadriceps muscle injuries.[61]

1.10.6 Head and neck injuries

The rates of head injuries in sports are increasing worldwide and research on the topic has recently been incremental.[140] Most concussions in sports are caused by contact mechanisms [141] and the risk in football is therefore logically considerable. In fact, 15% of all injuries in international football tournaments affect the head and neck and 11% of these injuries are concussions.[142] The head and neck injury incidence in European top-level football is considerably lower, with only 2.2% of all time-loss injuries affecting the head/neck region.[143] Fuller et al.[142] conducted a prospective study of head and neck injuries in international football tournaments and found that contusions, lacerations and concussions were the most common types of head and neck injury. Playing actions that were found to be most likely to cause a head or neck injury were aerial challenges with unfair use of the upper extremities.[142]

Neselius et al.[144] showed that repetitive minor traumatic brain injuries in Olympic (amateur) boxing, even without clinical or anamnestic signs of concussion, are associated with elevated levels of biomarkers indicating minor central nervous injury in the cerebrospinal fluid. They concluded that these repetitive injuries could be associated with an increased risk of chronic traumatic brain injury.[144] It could be hypothesised that heading in football could result in somewhat similar repetitive mild traumatic brain injuries. However, a recent study by Vann Jones et al.,[145] in which retired professional

football players were screened for cognitive impairment, did not reveal an elelevated risk of negative long-term consequences for cognition in football players. These findings suggest that heading would not be associated with negative long-term consequences, which is also supported by a systematic review of central nervous system injuries in sport and recreation by Toth et al.[146]

1.11 Foul play as an injury-causing factor

In 1863, the same year in which the FA was founded, the first rulebook for football was written in England. The objective was to unify the rules and the way football should be played and the players were expected never deliberately to commit fouls. Consequently, it was not until almost thirty years after the writing of the first rulebook that penalty kicks (then called "the kick of death") were introduced. Before that, there had been no referee on the field and it was the team captains' responsibility to reach a mutual agreement. With increasing popularity and competitiveness associated with the game, it became necessary to have independent agents to ensure that rules were applied and referees were introduced in 1891. After its foundation in 1904, FIFA has been responsible for developing and modifying the rules and today the laws of the game apply worldwide.[147]

Today, according to the laws of the game, a foul in football is an infringement of the rules, leading to a free kick or a penalty kick. This definition includes the use of excessive force and careless or reckless offences on opponents by players or teams.[140] In addition, the following requirements for a foul have been outlined by FIFA. (1) It must be committed by a player, (2) occur on the field of play and (3) occur while the ball is in play.[140]

Foul play is involved in the cause of injury in between 14-37% of all injuries in football [50, 52, 54-56, 83, 84, 111, 114] and in 35-80% of injuries resulting from contact between the players.[51, 52, 54, 73, 128, 129] Foul play is thus regarded as the most important extrinsic risk factor for injuries in football.[60]

The injuries caused by foul play are often sprains or contusions affecting the lower extremities (mainly the ankle, lower leg, thigh and knee).[50, 55] Although foul play injuries appear to be less severe than other injuries,[83] they are responsible for approximately 21-31% of all severe injuries.[82, 97, 111] Foul play injuries have been found to occur evenly between the two halves of a match.[55]

A video analysis of 8,572 tackles in international football tournaments found that 40% of the tackles involved a foul.[73] Junge et al.[116] found that 90% of football players were mentally ready to commit a ("professional") foul if required, depending on the score and importance of the match. This suggests that the incidence of foul play injuries could increase in certain match conditions, related to the current score, for example. Despite the recurring acknowledgement of the role of foul play in injury causation during football matches, detailed comparisons between foul play injuries and non-foul play injuries are rare in the literature.

There is no consensus on the definition of foul play injuries. Neither the consensus statement on injury definitions and data-collection procedures in studies of football (soccer) injuries,[81] nor the Union of European Football Association's (UEFA) model [75] has included a definition of foul play injuries. Some authors have based their definition of foul play injuries on the referees' decisions,[55, 82] while others base them on the team physicians' reports.[50-54] Fuller et al.[138] found that the proportion of contact injuries identified as fouls by the match referee varied depending on the area of the pitch and that they were lowest in the attacking goal area. Hot or cold environmental conditions do not appear to affect referees' decision-making ability.[149] However, referees' decisions may be affected by other environmental factors, such as home/away team status, match period and the size of the crowd.[150, 151] These findings may perhaps support the choice when it comes to defining foul play injuries according to team physicians' estimation, which is also based on the post-match assessment of the player.[54] Team physicians may also use complementary information, such as video material and the players' descriptions of the injury situations, as a basis for their decisions, whereas the match referees have to make a decision within a very narrow time frame and under pressure. Accordingly, the definition of a foul play injury applied in the present thesis is based on team physicians' reports.

Research on differences between foul play injuries and non-foul play injuries may be beneficial from an injury-prevention point of view. For example, in ice-hockey, changes to the rules of the game ("checking from behind rule") have reduced the number of severe spinal injuries.[152] There are also indications that severely sanctioning certain types of foul in football could reduce the number of concussions.[51] Fuller et al.[142] studied the epidemiology of head and neck injuries in international football tournaments and found that the use of upper limbs in vertical jumps was the most common reason for severe head injuries. As a result, the International Football Association Board instructed referees severely to sanction this type of foul and the number of head injuries dropped from 25 to 13, between the 2002 FIFA World Cup and the 2006 FIFA World Cup.[51] Further examples of changes to the rules, in order to prevent injuries, can also be found in sports including youth rugby and American football, among others.[153]

1.12 The variation in injury incidence during a football match

The time (minute) in the match when injuries occur has been the focus of many studies, resulting in somewhat varying results. In the 2010 FIFA World Cup, the number of injuries steadily increased towards the end of the match, with approximately 67% of the injuries occurring in the second half.[52] In the 2006 FIFA World Cup, the injury frequency was highest during the last 15 minutes of the first half,[51] while, in the 2002 FIFA World Cup, the incidence of injury was similar in both halves of the match, increasing towards the end of each half.[50] A study by Ekstrand et al.,[55] in which 23 first-team squads from the best teams in Europe were followed during the 2001-2008 seasons, revealed an increase in traumatic injuries over time towards the end of both halves, suggesting that tiredness may be an important factor. A study of English professional club team footballers showed a similar pattern, with an increasing number of injuries occurring towards the end of each half, with the incidence of injuries being significantly higher in the second half.[56]

There are considerable changes in the physical performance of players during the course of a match, some of which could speculatively affect the players' risk of suffering an injury. During the second half of football matches, the total running distance covered, and the match intensity, as well as the distances covered by sprinting and running at high intensity, decrease compared with the first half.[10, 12, 13, 21, 22, 26, 154] Players might aim to save energy during the second half by increasing the distance covered by walking and jogging and reducing the amount of running at high intensity,[13] in order to ensure that they last until the end of the match. Moreover, the recovery time between bouts of high-intensity running has been shown to become longer towards the end of the match.[21] Likewise, the frequencies of passing, ball possession and duels also appear to decrease closer to the end of the match.[154] In accordance with this, the lactate levels tend to decrease in the second half, compared with the first half.[10] However, an analysis of the effect of high-intensity physical efforts in top-level football on skill-related performance, measured as frequency and proficiency in ball possession, passing, duels and other match activities, did not show a significant decline in skill-related performance following match periods of the highest intensity.[154] Another study of top-level Italian and Danish footballers showed that the frequency of tackles was significantly lower during the second half compared with the first.[12] This suggests that players at the top level are able to maintain a high level of football skills, even during periods of fatigue.[154] In addition to any potential tactical advantages, substituting players also provides a mean for teams to maintain a higher level

of match intensity during the second half. A study of the match performance of top-level football players showed that substitute players performed 25% more of the high-intensity running and 63% more of the sprinting in the last 15 minutes of the match, compared with players who had played the entire match.[12]

1.13 Psychological risk factors for football injuries

The influence of psychological risk factors for injuries in sports has probably been traditionally undervalued.[155] For sports in general, high competitive anxiety, poor coping skills, a high anger trait and the outward expression of anger appear to be associated with a greater risk of injury.[155] Junge et al.[116] studied the psychological and sport-specific characteristics of European football players of different age groups and skill levels and found that football players with fewer previous injuries show fewer of these psychological characteristics associated with an increased risk of injuries, compared with football players with a history of more injuries. The results from the same study, by Junge et al.,[116] also indicate an association between a higher than average injury frequency and worrying about performance and/or peaking under pressure. Moreover, a lower score on a "free from worries" scale, life event stress and changing clubs during the previous season have all been associated with a higher risk of injury in football.[97, 116] Injured football players also describe themselves as "fighters" when trying to get past an opponent more often than uninjured players.[97] However, this might reflect poorer footballing skills among injured players, rather than a psychological characteristic, as some studies have shown an association between a lower skill level and a higher risk of injury.[97, 114]

Fuller at al.[156] assessed the relationship between professional football players' behaviour and injuries. The results indicated that injuries in football were likely to be caused by deliberately aggressive behaviour on the part of certain players.[156] Accordingly, Rascle et al.[157] found differences in football players' perceived legitimacy of aggression, partly dependent on the current score in the match. Junge et al.[116] found that most football players regard provocation and "hidden" fouls as part of the game. These authors also found that more than half the players who become the objects of hidden fouls tend to get their revenge for the foul by acting similarly.[116] Considering these findings, and the competitive nature of the game, match events could theoretically, as a result of a change in the psychological states of players, also affect the players' risk of suffering injuries, when it comes to contact injuries, for example.

1.14 Video analysis of football injuries

Video analysis of football injuries can optimally give the researcher the opportunity to study injury mechanisms and circumstances of injury as they occur in matches and video analysis methodologies have been increasingly used for epidemiological research on football injuries – specifically, for studying mechanisms of specific injuries,[68, 69, 132] for studying tackles,[71, 131] and for describing injury circumstances or playing actions leading to injury.[66, 67, 70, 72, 74, 158] Some of these studies have focused on injuries to specific body parts,[68, 69, 132] while others have focused on injuries in general.[66, 67, 70-72, 74] In addition, video analysis has been used to assess the accuracy of referees' decisions and to assess whether the laws of the game should be modified in order to prevent injuries.[129, 159] The methods have, so far, been found to be more useful for describing playing situations and athlete/opponent movements than for evaluating joint biomechanics.[160]

Hawkins and Fuller [66] were among the first to apply video analysis in epidemiological research on football injuries. They combined video recordings from matches in the 1994 FIFA World Cup with medical data obtained from newspaper reports (media coverage).[66] Later, these authors applied video analysis in analysing injuries in European Championship football, English Premier League football and English First Division matches.[67] Since then, Fuller et al.[71] have studied tackles and their propensity to cause injuries in international football tournaments. By combining tackle data, obtained through video analysis, with medical injury data, obtained through the prospective injury-surveillance system developed by FIFA/F-MARC,[53, 54] they were able to identify certain tackle parameters with a high propensity to cause injuries.[71] They found that tackles involving a clash of heads and two-footed tackles were the most harmful kind of tackles, for both tackling players and for the players being tackled.[71] They also identified tackles from the side as being especially harmful for the tackling players.[71] Based largely on the same methodology, Fuller at al. further assessed the level of player error associated with the process of tackling, the adequacy of the laws of the game related to tackling situations, as well as the referees' ability to identify fouls in tackling situations.[71, 73, 129] These studies provide a good example of how video analysis can be used successfully to identify playing actions with a high risk of injuries. However, these studies have not taken account of playing actions preceding the tackles, or the match circumstances in which they occur.

In contrast, Rahnama et al.[158] studied the injury risk associated with 16 playing actions in the English Premier League, during the 1999-2000 season. They used a video-based definition of injury, where an injury was defined as "receiving medical treatment on the pitch".[158] Rahnama et al.[158] analysed 10 matches, which resulted in almost 18,000 recorded playing actions, but, as there were relatively few injuries, the method did not enable the drawing of any conclusions about the risk of injury associated with these actions. In 2003, Andersen et al.[72] described a video-based method, FIA (Football Incident Analysis), for analysing what were referred to as "injury risk incidents", using football-specific variables. FIA was developed as a descriptive tool for analysing playing actions and match circumstances leading to injury risk incidents and this method has since been applied in several studies.[70, 74, 159, 161]

According to the FIA methodology, an injury risk incident refers to any situation in which the match is interrupted by the referee, or a player is on the ground for more than 15 seconds, or the player appears to be in pain or receives on-pitch medical treatment.[70, 72, 74, 159, 161] Some previous studies have combined video analysis data, obtained by FIA, with medical data based on reports from teams' medical personnel.[70, 74] These studies have shown that linking non-contact injuries with the injury risk incidents is often difficult, in contrast to contact injuries.[70, 74] Bjørnboe et al.[161] analysed injury risk incidents in professional Norwegian male football by applying FIA and included an analysis of tackle situations, as proposed by Fuller et al.[71] However, they did not include medical data in the analysis, making it impossible to identify actions that resulted in injuries. Using FIA, injury risk incidents are categorised according to 19 variables, each with two or more categories related to playing actions preceding the incident.[72] However, no specific patterns for the playing situations leading to injuries have yet been identified by applying the FIA methodology. FIA has been used as a descriptive tool,[70, 72, 74, 159, 161] but the injury risk associated with individual variables has not previously been studied.

1.15 Prevention of football injuries

Considering the immense popularity of football and the potentially serious consequences of injuries, there is a huge need to develop strategies aimed at preventing football injuries. The first randomised study of injury prevention in football originated from Sweden in the early 1980s; Ekstrand et al.[88] showed that football injuries could be reduced by up to 75% with a multicomponent injury-prevention programme, supervised by doctors and physiotherapists. The programme included interventions, such as correction of training, choice of optimal equipment, ankle taping, controlled rehabilitation of injuries and excluding players with a high level of knee instability, as well as educational measures about the risks of injury during training and the importance of disciplined play.[88] The prevention programme was based on a series of prospective epidemiological studies, also conducted by Ekstrand et al., of risk factors for football injuries.[162-164] The success of the prevention programme therefore serves as an encouraging example of how epidemiological research can be optimally applied to improve players' health.

Since the early 1980s, a great deal of research has been conducted, both in order to identify new risk factors for injuries and aimed at developing prevention strategies based on the identified risk factors. Some studies have aimed at preventing specific injuries, or injuries to specific locations, while other more generalised prevention programmes have aimed to reduce the general injury incidence.[59, 165] Current data from 44 top-level football teams worldwide demonstrate that clubs at the highest level include an injury-prevention programme in their training.[166] The same study showed that 73% of the clubs applied both individualised and generalised prevention programmes for their players.[166] Some of the scientific and clinical advances resulting from these preventive strategies are summarised below.

1.15.1 Generalised injury-prevention programmes

The first generalised, or multi-component, prevention programme was developed by Ekstrand et al.[88] in the 1980s. The authors of another pioneering study from the same period, applying injury surveillance in football, recommended that the emphasis should be placed on an adequate warm-up in order to prevent injuries.[164] At the beginning of the millennium, Junge et al.,[89] designed a generalised injury-prevention programme for amateur youth football. The programme consisted of the education and supervision of both coaches and players, in order to improve the quality of training.[89] Essential components included warm-up, cool-down, taping of ankles with instability, promotion of fair play and a series of specific coordination, stability and strength exercises.[89] The results of the study revealed a 21% reduction in injuries compared with the control group.[89]

Encouraged by the promising results, a programme called "The 11" was developed and tested countrywide, in Swiss male and female amateur football, with the cohort including players from different age groups.[59] "The 11" was a programme based on eleven components, including ten exercises aiming at core stabilisation, eccentric exercises, improved proprioception, dynamic stabilisation and plyometric exercises, as well as a final 11th component: the promotion of fair play.[59] The results of the countrywide study showed a reduction of 12% in match injuries and 25% in training injuries, with an especially high reduction in non-contact injuries (27%), for teams applying "The 11", compared with teams that did not.[59] Steffen et al.,[167] from the Oslo Sports Trauma Research Centre (OSTRC; wwww.ostrc.no), tested "The 11" in a randomised, controlled trial of female youth football players and found no significant injury-preventive effect. These authors speculated that a reason for the lack of significance was poor compliance with the programme.[167] Likewise, van Bejsterveldt et al.[76] studied the injury-preventive effect of "The 11" on male amateur players in the Netherlands and found no preventive effect.

Consequently, an improved version of the programme, now called "The 11+", was developed.[168] The new programme was designed to replace the usual warm-up, aiming at improving strength, awareness and neuromuscular control, during both static and dynamic movements.[168] "The 11+" significantly reduced the risk of overall injuries, severe injuries and overuse injuries, in a cluster-randomised, controlled trial in Norwegian female youth

football players.[168] Another study, by Soligard et al.,[169] showed that the degree of compliance did in fact affect the injury-preventive effect of "The 11+", with players with high compliance having a significantly lower injury risk than players with intermediate compliance. Compliance is thus an important issue to take into consideration when designing injury-preventive measures. Positive effects of "The 11+" on functional balance, neuromuscular control, knee flexor strength, static and dynamic balance and thigh muscle strength have also been reported.[170] "The 11+" programme is accessible online at www.f-marc.com/11plus/manual/. It has three parts, with durations of eight, 10 and two minutes respectively. The first and the third part include different types of running exercises. The first part includes running exercises performed at slow speed, while the third part comprises moderate- to high-speed running exercises. The second part of the programme comprises six sets of exercises, aiming at improving core and leg strength, balance and agility. The exercises in the second part can be performed at three levels of increasing difficulty.

Moreover, other generalised studies have shown encouraging results. A study by Heidt et al.[171] of injury prevention in female youth football players showed promising results after applying a seven-week preseason conditioning programme. Another cluster-randomised, controlled trial, by Emery et al.[172] showed significant reductions in all types of injury in Canadian youth football (male and female), as a result of a football-specific neuromuscular prevention programme.

The programme included dynamic stretching, eccentric strength, agility, jumping and balance exercises, as well as home-based balance training with a wobble board and stretching.[172] Further advantages of neuromuscular training programmes are that they are easy to implement and have low costs [173] and this may increase compliance.

1.15.2 Preventive programmes with a more specific approach

The injury-prevention programmes designed to prevent specific football injuries have logically concentrated on the most common, or severe, injuries. As discussed above, a total of 29-58% of all injuries in football affect the thigh, the ankle, or the knee. Consequently, a great deal of research has focused on the prevention of hamstring injuries,[134-136] knee injuries [174-177] and ankle injuries [178-180] in football. ACL injuries, which are often severe and result in long lay-off periods from football, are especially problematic knee injuries.[79, 91] Many studies of the prevention of knee injuries have therefore focused specifically on ACL injuries.[174-177]

As hamstring injuries are the most common time-loss injuries in football, the interest in ways of preventing them is hardly surprising. Askling et al.[135] were able significantly to reduce hamstring injuries in Swedish top-level male football players, who performed a hamstring-specific preseason training programme, compared with players who performed ordinary training. The training programme consisted of a total of 16 training sessions during a 10-week period during the preseason and was specifically designed for the eccentric overloading of the hamstrings, although it also included concentric exercises.[135] The study by Askling et al.[135] is rare, as it only focuses on top-level players. Likewise, the results of a study by Árnason et al.[134] showed a significant reduction in hamstring injuries in Norwegian and Icelandic top-level football, by applying an eccentric strength training programme of the hamstrings (the Nordic hamstring). The preventive effect of the Nordic hamstring exercise on acute hamstring injuries was later shown in a randomised, controlled trial involving Danish male top-level and amateur players.[136]

Considerable efforts have also been made to develop prevention programmes for ACL injuries. In 1996, Caraffa et al.[176] demonstrated that ACL injuries could be reduced in amateur and semi-professional football by gradually increasing proprioceptive training with a wobble board. On the other hand, Söderman et al.[181] tested the injury-preventive effect of balance-board training on lower leg injuries, in a randomised intervention involving Swedish female football players, and found no preventive effect. The authors suggested that possible explanations for the contradictory results, in comparison with the results of Caraffa et al., could reflect differences in study populations, differences in the total training exposure, or an unexpectedly high drop-out rate.[181]

Low compliance can be a major issue, even with specific prevention programmes, as has been demonstrated by a randomised, controlled trial, conducted by Engebretsen et al.[182] on Norwegian 1st, 2nd and 3rd division football players, in which only 29% of the players in the intervention group followed the programme. They did, however, show that the players who ran an increased risk of an ACL injury could be identified by a simple questionnaire.[182] The results of a numbers-needed-to-treat analysis of neuromuscular training programmes for preventing

ACL injuries in female athletes supported the use of neuromuscular training in the prevention of ACL injuries.[175] Hägglund et al.[183] conducted a randomised, controlled trial, in which the injury-preventive effect of a neuromuscular training programme was tested on adolescent amateur female football players. The results presented by Hägglund et al.[183] showed that players in the high-compliance group had significant reductions in their ACL injury rates, compared with players with low compliance. Players with high compliance also had significant general reductions in severe knee injury and any acute knee injury rates, compared with players with low compliance.[183] These results further emphasise the importance of considering compliance issues, when designing injury-prevention programmes. Furthermore, a cost-effectiveness analysis of prevention and screening for ACL injuries in youth athletes showed that neuromuscular training was a cost-effective measure for reducing both the costs and morbidity of these injuries.[173] Alentorn-Geli et al.[174] reviewed the prevention programmes aimed at reducing ACL injuries in football and concluded that multi-component programmes are to be preferred, compared with single-component programmes, and that the injury-preventive measures should not be limited to the preseason. The authors suggested that compliance issues may be the most important single limiting factor of studied interventions.[174] As discussed previously, ACL injuries are a major concern in female football and many of these studies have included female players. It is therefore not surprising that a recent systematic review of prevention strategies for non-contact ACL injuries, for male athletes specifically, demonstrated that the data available to date are scarce and that it is therefore impossible to draw conclusions about optimal preventive strategies.[177]

Like the strategies designed to prevent hamstring injuries and ACL injuries, strategies for preventing injuries to other specific body parts have been developed and studied. In 1985, Tropp et al.[178] recommended co-ordination training on an ankle disk in the rehabilitation of ankle injuries, in order to prevent recurrent injuries.[178] Later, proprioceptive training in the form of progressive ankle-disk exercises was in fact shown to be effective in reducing ankle sprains in a randomised, controlled trial involving male football players with a history of ankle sprain.[179] Moreover, balance training appears to be useful for preventing ankle injuries in youth football players.[180]

1.15.3 Challenges in football injury prevention, and future perspectives

Despite these encouraging efforts, the need for epidemiological research on football injuries remains high. van Bejsterveldt et al.[185] conducted a systematic review of the effectiveness of exercise-based injury-prevention programmes for football players. They concluded that some of the contradictory findings were likely to be due to differences in study samples (with regard to gender and level of play), to differences between the intervention programmes (with regard to content, as well as frequency and duration of training) and to compliance issues.[185] Accordingly, Olsen et al.[115] systematically reviewed the prevention strategies available, specifically for football, and concluded that more research through injury surveillance is necessary, in order to identify factors related to the occurrence of injuries and eventually to design satisfactory prevention strategies. This conclusion is further supported by several other researchers.[76-80]

As previous injury has been shown to be a significant risk factor for football injuries,[84] the controlled rehabilitation of previous injuries is regarded as an important component of injury prevention. The controlled rehabilitation of injuries was one component of the first injury-prevention study in football, conducted by Ekstrand et al.[88] Far more recently, Hägglund et al.[186] conducted a randomised, controlled trial, which showed that re-injuries could be significantly reduced by controlled rehabilitation programmes implemented by coaches.

Convincing coaches and team management to commit to injury-preventive measures may be a challenge, but it is still a crucial component of successful injury prevention.[58, 59, 61, 89, 187] As managers and coaches have important decision-making power within teams, one important future challenge in injury prevention is to convince these persons to engage in injury prevention.[58] The 11-year follow-up of the UEFA injury study by Ekstrand et al.[61] highlights the need for good internal communication between the medical staff and the coaching staff. The authors discussed the problem of limited influence of teams' medical staff on training load, for example.[61] Likewise, Bizzini et al.[170] encouraged the development of good communication between medical professionals and coaches. F-MARC used famous coaches and players as "ambassadors" for the "FIFA 11+" programme, which helped to get the researchers' message through to the coaches.[170] Bizzini et al.[170] also stated that the choice of instructors among persons engaged in football, who "speak the football language", is important for reaching players and other team staff. The importance of injury prevention, also from the perspective of team management and coaches, is also accentuated by the results of Hägglund et al.,[62] which demonstrated a negative effect of injuries on team success. Futhermore, engaging team management in injury prevention may be crucial in order to avoid the frequent limitation of low compliance in several football injury-prevention studies, which appears to be a major challenge for future research.[115, 167, 174, 185, 188] MaCall et al. investigated the preventive strategies of 44 different top-level football teams worldwide and found that clubs generally follow research guidelines for preventing injuries, but that the perceptions and practices in clubs are not always well supported by research literature.[166] One further question that needs to be answered by future studies is probably, therefore, whether the efficacy of currently applied practices can be scientifically demonstrated.

1.16 Why Studies I-IV were conducted

Considering the consequences of football injuries, discussed above, identifying the risk factors for injuries through epidemiological research is necessary and represents a crucial first step in designing injury-preventive measures.[56] This thesis aims to contribute to the epidemiological research by identifying potential game-related factors that are associated with the risk of injury during a match in FIFA World Cup football.

As football is a sport of a highly competitive nature, especially at the top level, it appears logical that certain match events that are an essential or inevitable part of the game – such as changes in the score, injuries, red and yellow cards and foul play – could affect the team strategies, the players' attitudes and precautions, match intensity and, possibly, the incidence of injuries within a match.

Identifying time periods with a high injury incidence within a match may be of use to players and team personnel, as it could enable them to take precautions during these periods. In a similar manner, the identification of playing actions and match circumstances associated with a high risk of injury, by video analysis, may provide useful information from an injury-prevention perspective.

As discussed above, the highest injury incidences in international football tournaments have been recorded during men's World Cup football, which highlights the need for epidemiological injury research in that population. Prospective injury surveillance has been applied in FIFA tournaments since 1998.[45] Research projects applying the validated methodologies to similar study populations will therefore have a wide framework for comparing results and discussing their significance, based on previous studies. In addition, as national teams from all continents are represented in a FIFA World Cup, this also provides a unique platform for an epidemiological injury study, as it includes players and teams with different ethnic origins and (playing) cultures.

AIMS

The general aim of the thesis was to investigate possible associations between game-related factors and match events and the players' risk of suffering injuries, in international (national team) top-level male football tournaments (FIFA World Cups). The general hypothesis of this thesis was that crucial match events are associated with the players' risk of suffering injuries.

2.1 Specific aims of Studies I-IV

In Study I, the aims were to study

- Whether there is a variation in the injury incidence related to changes in the score in international top-level male football
- Whether the playing position had any effect on the injury incidence
- The possible association between recovery time between matches and injury incidence.

In Study II, the aim was to study a possible relationship between crucial match events that interrupt the match (and hypothetically change its course) and injuries in international top-level male football. Specifically, the emphasis was goals, injuries, as well as red and yellow cards, and their association with injury incidence.

In Study III, the aims were to study

- Differences between foul play injuries and non-foul play injuries with regard to their characteristics and the match circumstances in which they occur
- A possible association between the number of fouls and injuries per match.

In Study IV, the aims were to use video analysis to

- Describe injuries and injury risk incidents resulting from contact between players in men's World Cup football and to explore whether any independent predictors of injury could be found among the variables chosen for analysis
- Analyse all injury risk incidents and injuries resulting from tackles and to assess whether specific tackle parameters had a higher propensity to cause injuries than others.

MATERIAL AND METHODS

The material for the present thesis consisted of data from the 2002 (Korea-Japan), 2006 (Germany) and 2010 (South Africa) FIFA World Cups for men and was obtained from three different sources: (1) injury-surveillance data, (2) official match statistics and (3) video recordings of matches. In each of the three FIFA World Cups, a total of sixty-four matches were played by 32 participating teams (a total of 736 players).

3.1 Data sources

3.1.1 Injury data

The injury data, in the form of injury report forms, was obtained through a prospective injury-surveillance system, developed under F-MARC, which has been implemented at FIFA tournaments since 1998.[50-54] The team physicians, representing the different national teams participating in the tournaments, provided the injury data on structured injury report forms, based on post-match assessments of injured players.

The data-collection methodology followed the current international consensus statement on injury definitions and data-collection procedures for epidemiological research on football injuries [81] and ethical approval for injury surveillance was obtained. An injury was defined as any physical complaint, incurred during the match, that received medical attention from the team physician, regardless of the consequences with respect to absence from match play or training.[50-52, 54]

The injury report forms contain details of the type and location of injury, team of the injured player, the shirt number of the player, the time (minute) in the match when the injury occurred, the circumstances of injury (non-contact, contact and the possible involvement of foul play), the consequences of injury (referees' sanction and possible treatment) and an estimate of the resulting time loss from participation in football. The development and implementation of the data-collection procedures are described in detail in previous studies based on the collected data.[50-54] Before the tournaments, all the team physicians were educated in detail on how to fill in the report forms, in order to minimise discrepancies.

The total number of injury reports included in the data was 441, consisting of 171 injury reports from the 2002 FIFA World Cup, 145 injury reports from the 2006 FIFA World Cup and 125 injury reports from the 2010 FIFA World Cup. The details of the injury data are presented in three previous studies of the three respective FIFA World Cups.[50-52]

3.1.2 Match statistics data

The match statistics data were obtained from the official tournament statistics, available on FIFA's official website.[189] For each of the 192 matches played in the three tournaments, the following data were obtained:

- The total number of goals
- The time (minute) of goals
- The total number of red and yellow cards
- The time (minute) of red and yellow cards
- The length (in minutes) of match periods played with different scores (current match result)
- The total number of fouls
- The number of full recovery days before the match (separately for each of the two teams)

Moreover, the playing position of the injured players was assessed from the tournament statistics on the official website.[189] The shirt numbers of the injured players (included in the injury-surveillance data) were used, in order to recognise the players of interest from the tournament statistics. The baseline data, with regard to the number of injury reports and match statistics, are presented in Table 1.

3.1.3 Video analysis data

The video analysis data consisted of full video recordings of all 192 matches played in the three tournaments, provided by FIFA. The video recordings included sequences captured from different angles, by several high-quality cameras, with numerous slow-motion sequences of contact situations included. All video recordings were reviewed by one of the authors of Study IV (LL), who is experienced in the video analysis of injuries and injury risk incidents. Data were obtained using video analysis methodologies based on previous research. These video analysis methodologies are described in detail in this thesis (under the subheading "Methods for video analysis").

3.2 Methods used in Studies I and II

3.2.1 The association between injury incidence and the current score, as well as teams' drawing, winning or losing status

To calculate the injury incidences depending on the current score in the match, the matches were divided into match periods based on the current score and injuries

Table 1. Baseline data.

Tournament	FIFA World Cup 2002	FIFA World Cup 2006	FIFA World Cup 2010
Number of matches	64	64	64
Number of teams	32	32	32
Number of players	736	736	736
Number of yellow cards	271	345	261
Number of red cards	17	28	17
Number of goals	161	147	145
Number of injury reports	171	145	125

were divided into the same score groups accordingly:

- 0-0
- Even score with goals scored
- One-goal difference between the teams
- Two or more goal difference between the teams

No previous research was available for choosing the pre-determined criteria for dividing the match based on the current score. This grouping was partly chosen in order to ensure groups large enough to allow comparison between the groups. The time (minute) of injuries, obtained from the injury-surveillance data, was compared with the match statistics, in order to divide the injuries according to the corresponding match periods based on the current score. The matches were also divided into three groups, based on the teams' drawing/winning/losing status. The injuries were again grouped according to these match periods, to calculate injury incidence. In the same way as for the score groups, the injury report data (team of the injured player and minute of injury) were used to divide the injuries according to the corresponding match periods, based on the teams' current drawing/losing/winning status.

3.2.2 Assessment of the relationship between PGDIs and injury incidence

According to the hypothesis, there would be an association between yellow or red cards, injuries and goals and injury incidence. Yellow and red cards, injuries and goals were therefore defined as potentially game-disrupting incidents (PGDIs). These specific factors were included in the definition of PGDIs based on two main criteria:

1. Both the total numbers, and the minutes when they occurred, had to be documented in the match statistics

2. They had to have a potential impact on the course of the match that could affect several players simultaneously.

Yellow and red cards are sanctions from the referee, given out when a player does not behave fairly. A yellow card is awarded for offences including unsporting behaviour, dissent by word or action, persistent infringement of the laws of the game and delaying the restart of play, among others.[9] A red card, which leads to the expulsion of the player breaking the rules, is sanctioned for offences such as serious foul play, violent conduct, spitting at another player/or any other person, denying an opponent the opportunity to score a goal by using a hand, or by denying an obvious goal-scoring opportunity by a foul, using offensive, insulting or abusive language, or receiving a second yellow card within the same match.[9]

In the present thesis, the matches were divided into two match periods: (1) minutes of PGDIs and the following five-minute periods and (2) other match periods. The choice of a five-minute period was based on previous research on players' physiological performances during matches, showing that matches are typically characterised by five-minute periods of high-intensity running, followed by five-minute periods of lower intensity running, compared with the average level during matches.[12] In order to calculate injury incidences during the match periods based on the timing of PGDIs, all injuries were divided into two groups, according to the corresponding match periods.

For injuries, the times were obtained from the injury-surveillance data and, for the other PGDIs, the times were obtained from the match statistics. In cases in which a subsequent PGDI followed within a five-minute period from a prior PGDI, only the minutes before the subsequent PGDI were calculated for the period following the prior PGDI. This was done in order not to include overlapping minutes in the analysis and thus exceed the number of minutes actually played in the matches.

For further assessment of the association between the occurrence of PGDIs and injuries during different match periods, the match was divided into six 15-minute periods. The possible extra-time during the knock-out stages of the tournament was included in the event it was played, in contrast to possible minutes of additional time at the end of the half, which were excluded. PGDIs (injuries excluded) were divided according to the minute in which they occurred into groups corresponding to the six match periods. Similarly, in order to calculate the incidence of injury during these match periods, all injuries were divided (separately from the other PGDIs) into groups according to the corresponding match periods. The injuries had to be excluded from the other PGDIs for this part of the study.

3.2.3 Assessment of differences in injury incidence between playing positions

The playing positions of the injured players were obtained from the official tournament statistics on FIFA's website. The shirt number and team of the injured player, obtained through the injury-surveillance data, were used in order to recognise the correct player from the tournament statistics. In order to determine the match exposure for the different playing positions, the injuries were divided into groups, according to the playing position of the injured player. As the tournament statistics do not include the tactical formations used by teams, a hypothetical formation was chosen in order to determine the relative exposures of the different playing positions, necessary for calculating the incidence of injury. Based on previous research,[130] a hypothetical 1:4:4:2 (one goalkeeper, four defenders, four midfielders and two forwards) formation was applied. The injury incidences for the different playing positions were calculated and compared.

As was done for all injuries, the injury incidences for the outfield playing positions (defenders, midfielders and forwards) were further calculated separately during match periods, based on teams' drawing/losing/winning status.

3.2.4 Assessment of a possible association between recovery time and injury incidence

The number of full recovery days between all matches was assessed, for each team separately, from the tournament schedules obtained from FIFA's official website. Only matches after the first round of the tournaments were included, as the previous matches of players were most likely played at club level and the recovery times for players within the same national team would therefore have been different. The total numbers of injuries per team per match were also assessed for all matches played after the first round of the tournament. The matches (per team) were then grouped according to the number of recovery days and the injury incidence for each match group was calculated.

3.3 Methods used in Study III

The judgement of the involvement of a foul in injury causation was determined by the respective team physician, caring for and assessing the injured player, who also filed the injury report.[54] All injuries for which the team physicians had documented the foul/non-foul status were included in the analyses.

3.3.1 Comparison of injury severity between foul play injuries and non-foul play injuries

The definition of injury severity was based on the duration (in days) of the lay-off from match play or training resulting from the injury.[75, 81] The lay-off time was estimated by the team physician, based on the post-match assessment of the injured player. In accordance with the consensus statement,[81] the injuries were categorised as slight (0 days), minimal (1-3 days), mild (4-7 days), moderate (8-28 days) and severe (over 28 days of absence). Both the total numbers of foul play injuries and non-foul play injuries within each category of injury severity were calculated. Moreover, the median numbers of estimated lay-off days were calculated for both foul play injuries and non-foul play injuries for comparison.

3.3.2 Assessment of differences between foul play injuries and non-foul play injuries during different match periods

To assess and compare the incidences of foul play injuries and non-foul play injuries during different match periods, the matches were divided into different match periods, as described previously, based on teams' drawing/losing/winning status, and in six chronological fifteen-minute periods (and possible extra time).

Subsequently, both foul play injuries and non-foul play injuries were grouped separately, according to the corresponding match periods. As for all injuries in the previous parts of the thesis, the grouping of injuries according to the corresponding match periods was based on comparisons of match statistics data and the time of injury (obtained from the injury reports).

3.3.3 Comparison of foul play and non-foul play injury incidences between the playing positions

The calculations of injury incidences for the different playing positions followed the same methodology as described earlier for comparing the injury incidences between the playing positions. In this case, the calculations were made separately for foul play injuries and non-foul play injuries, in order to enable comparisons.

3.3.4 Assessing a possible association between the number of fouls and injury incidence in a match

The total number of fouls in all 192 matches was obtained from the match statistics. Similarly, the total numbers of injuries in each match were obtained from the injury-surveillance data. Comparisons of the injury report data and match statistics made it possible to link the data from the two sources. The matches were then grouped into four groups, based on the total number of injuries per match:

1. 0 injuries
2. 1-2 injuries
3. 3-4 injuries
4. 5 or more injuries

No guidelines were found in the literature on how to divide matches based on the total number of injuries. For the present thesis, the injuries were therefore grouped in four groups, in order to ensure that the group sizes were suitable for statistical comparison. The mean number of fouls within each match category, based on the total number of injuries in the match, was then calculated for subsequent comparisons of the means.

3.4 Methods used in Study IV

3.4.1 Definitions

The definition of injury was the same as that applied in Studies I-III and was thus in accordance with previous epidemiological studies of injuries in World Cup football.[50, 52, 54, 81] Furthermore, the following definitions for injury risk incidents and tackles were applied.

- A contact injury was defined as an injury resulting from physical contact between players.
- An injury risk incident was defined as any situation, identified on video recordings, in which the match was interrupted by the referee, or a player was on the ground for more than 15 seconds, or the player appeared to be in pain or received medical treatment. This definition is in accordance with the FIA (Football Incident Analysis) methodology.[70, 72, 74, 159, 161]
- A contact injury risk incident was defined as an injury risk incident that resulted from physical contact between players.
- A tackle was defined as any event, identified on video recordings, that occurred during the normal course of the match and involved physical contact between two or more players while one or more of the players was challenging for possession of the ball.[71, 73, 129-131]

3.4.2 Variables used in the video analysis

From FIA

Eight FIA variables [72] of interest, each with two or more categories, four of which were slightly modified, were included. The variables were used to analyse all contact injury incidents identified on the full video recordings of matches. As described in the original method by Andersen et al.,[72] the four FIA variables included, without modifications, were:

- **Ball possession**, with two categories: *defence or attack*
- **Attack type**, with four categories: *set play*, *breakdown attack*, *long attacks including long pass*, *or long (organised) attacks*
- **Degree of balance in opponents' defence**, with three categories: *good*, *average*, or *poor*
- **Player's movement intensity**, with two categories: *high intensity* or *low intensity.*

For the additional four FIA variables, which were included in the analysis, slightly modified variable categories were used. The rationale for these modifications is described below. These variables (and categories) were:

- **Player's position**, with four categories: *defender*, *midfielder*, *forward*, or *goalkeeper*[121]
- **Player's action with the ball**, with six categories: *dribbling*, *heading*, *deflecting the ball*, *kicking the ball*, *goalkeeper action*, or *no action with the ball*
- **Player's attention**, with four categories: *towards primary duellist*, *towards the ball*, *towards a team-mate*, or *other*
- **Referee's decision**, with two categories: *foul or non-foul.*

According to the original FIA methodology, the variable "playing position" had seven categories. The present thesis instead used four categories, in order to enable comparisons of the results with the results obtained from Studies I and III. The variable "player's action with the ball", as described in the original FIA methodology, had 14 categories, some of which were combined for the purpose of the present thesis, in order to avoid the previously described problem of having too few cases in some of the variable categories.[72] For the variable "player's attention", a new category ("other") was added to the previously described categories, as the player's attention was sometimes directed somewhere else (i.e. coach, crowd, the pitch, the goal, unknown etc.). For the variable "referee's decision", the category "foul" was modified to comprise the previously described categories "free kick for", "free kick against", "yellow card" and "red card". This was done, again, in order to avoid the problem identified in previous studies; too many categories with a small number of cases, which was the main reason for combining categories in the present thesis.

In the tackle analysis

All contact injury risk incidents identified on the video recordings of matches that matched the definition of a tackle applied in the present thesis were further analysed using tackle parameters, as proposed by Fuller et al.[71] One new category (described below) was added within the tackle action parameter for the analysis in the present thesis. The tackle parameters were:

- **Tackle direction**, with three categories: *front*, *side*, or *behind*
- **Tackle mode**, with three categories: *on feet*, *sliding in*, or *vertical jump*
- **Tackle action**, with six categories: *one-footed*, *two-footed*, *use of arm/hand*, *upper body contact*, *clash of heads*, or *combination*.

The "combination" category was the new category added for the present analysis and it included tackles involving more than one simultaneous tackle action, as some tackles were found to involve simultaneous tackle actions with the potential to cause injuries.

Added variables

In addition to the variables included from FIA and the tackle parameters, two variables were added to the video analysis:

- **Current score** (for the team in focus for the incident), with three categories: *losing*, *drawing*, or *winning*)
- **Match period** (minutes *0-15*, *16-30*, *31-45+*, *46-60*, *61-75*, *76-90+*, or *extra time*.

The two factors were added, as, in Studies I-III, they had been observed to be associated with the variation in injury incidence during matches and therefore to enable comparisons of the results of the video analysis with those based on injury report data and match statistics only.

3.4.3 (Original) FIA variables excluded from the video analysis

The following 11 FIA variables (*with categories*), included in the original FIA methodology,[72] were excluded from the present analysis: "positioning" (*one-on-one situation*, *not one-on-one situation*); "player's role" (*first defender*, *other defender*, *first attacker*, or *other attacker*); "duel type" ((1) in duel: *heading duel-active*, *tackling duel-active*, *screening duel-active*, or *running duel* and *other* and (2) *not in duel*); "ball-winning situations" (*at the moment of ball winning*, *after ball winning*, *after second ball*, or *not ball-winning situations*); "player's movement direction" (*forward*, *sideways*, *backward*, *no movement*); "tackling type" (*being tackled*, *not being tackled*, *tackling*, *not tackling*); "type of incident risk action" (*against first attacker towards "back room"*, *against first attacker elsewhere*, *against first defender*, *action away from the ball*, *actions against other players*); "degree of individual ball control" (*high level of control*, *low level of control*); "team action before injury incident" (*long pass*, *short pass*, *flick*, *cross*, *deflection*); attack effectiveness (*effective attack*, *non-effective attack*); "localisation on the field" (*defensive third*, *midfield zone 1*, *midfield zone 2*, *attacking third*, *score box*).

The rationale for excluding the first eight of the original FIA variables was that some of the variables included in the present study ("player's action with the ball", "player's movement intensity" and the tackle parameters) were considered fully to describe, in the context of the present study, a player's actions, role and the contact mechanisms involved in the contact injury risk incidents. Similarly, the teams' actions and situations were considered to be sufficiently described by the included variables: "ball possession", "attack type" and "degree of balance in the opponent's defence") and "team action before injury incident" and "attack effectiveness" were therefore excluded. Ultimately, the variable "localisation on the field" was excluded, as the present analysis focused primarily on match circumstances, playing actions and tackle parameters, rather than the localisation of the incident on the field, and, additionally, as the playing action variables included in the present study, such as "attack type", were not always directly related to a specific location on the field.

3.4.4 Combining video analysis data with injury-surveillance data

All contact injury risk incidents identified on the full video recordings of the 192 matches played were included in the analysis. Likewise, all contact injuries identified from the prospective injury-surveillance data were preliminarily included. The details of each contact injury risk incident (on video) were compared with the injury-surveillance data (injury report forms), in order to identify the contact injury risk incidents that could be linked with post-match injury reports (i.e. the contact injury risk incidents that resulted in an injury). Data available on the injury report forms (see subheading "Data sources") were used to link contact injury risk incidents with contact injuries. Specifically, the player's shirt number, the time of injury, and the injury type and location were the factors mainly used in order to link incidents with injuries.

3.4.5 Assessment of injury risk associated with variables and variable categories

To assess the injury-prediction value of the FIA variables and the added variables, the ratios of (1) contact injury risk incidents, as defined in the FIA methodology, which could not be linked with a post-match injury report, and (2) contact injury risk incidents, which could be linked with post-match injury reports, per all contact injury risk incidents were calculated for all variable categories. These ratios were compared in order to identify variables and variable categories that were associated with a relatively high risk of injury.

The contact injury risk incidents identified by video analysis, which fulfilled the definition of a tackle, were analysed separately, as they formed a separate and predetermined group of variables. Like with FIA variables, the numbers of contact injury risk incidents identified as tackles that could be linked with a post-match injury report were calculated and compared with those of contact injury risk incidents that could not be linked with a post-match injury report.

3.5 Statistical analysis

3.5.1 Statistical analysis of the injury report data and match statistics (Studies I-III)

The incidence of injury was calculated by using the formula: (number of injuries x 1,000 match hours)/(minutes of exposure/60) x n players exposed and expressed as the number of injuries per 1,000 match hours.[81] The numbers of players used for calculating exposure time were as follows:

- 22 for calculating injury incidence for the match periods based on the current score,
- 22 when calculating injury incidences during five-minute periods following PGDIs and during other match periods,
- 22 for calculating injury incidences during the chronological 15-min match periods,
- 11 for calculating injury incidences based on teams' drawing/losing/winning status and
- 11 for calculating injury incidences for the groups based on the number of recovery days between matches.

To calculate injury incidences for the different playing positions, a hypothetical 1:4:4:2 playing formation (one goalkeeper, four defenders, four midfielders and two forwards) was applied, in order to assess the relative exposures for the different playing positions.[130]

Any consequences of possible expulsions on the number of players exposed were not taken into account in the analyses. Furthermore, the minutes of additional time were not taken into account as exposure time. On the other hand, the 30 minutes of extra time were included, when extra time was played.

Injury incidence rates (per 1,000 match hours) with 95% confidence intervals (95% CI) were calculated assuming a Poisson distribution. Incidence rate ratios (IRR) and the test for a significant trend in injury incidence rates across the different groups, as well as in relation to days of recovery, were calculated using Poisson regression models or negative binomial regression models, when appropriate. The 95% CIs for numbers of PGDIs per match period were obtained by bias-corrected bootstrapping (5,000 replications).

Frequencies, cross-tabulations and the chi-square test were applied when comparing the injury types and injury locations of foul play injuries and non-foul play injuries. To compare the medians of lay-off time (expressed in days) resulting from foul play injuries and non-foul play injuries respectively, the Mann-Whitney test was used.

A bootstrap-type analysis of variance (ANOVA) was used to evaluate the statistical significance for the hypotheses of linearity between the total number of fouls and the total number of injuries per match. In the event of a violation of the assumptions (non-normality), a bootstrap-type test was used. The normality of the variables was tested using the Shapiro-Wilk W test.

The incidences of injury for foul play injuries and non-foul play injuries, during the different match periods, according to teams' drawing/losing/winning status at the time of injury, as well as according to player position, were analysed with random-effect Poisson regression models for panels. The model included a random intercept to account for clustering within a match, as well as fixed effects for injury causation (foul vs. non-foul), as well as for match time (match period), for the teams' current drawing/losing/winning status and for playing position. The interaction term allowed assessments of differences in injury causation (foul vs. non-foul) between the different match periods, between the groups based on teams' drawing/losing/winning status and between playing positions.

The level of significance was set at p-values of < 0.05. The STATA 12.1, StataCorp LP (College Station, TX, USA) statistical package was used for the analyses.

3.5.2 Statistical analysis of data obtained by video analysis (Study IV)

Logistic regression models with robust estimates of variance were used to investigate the variables (FIA variables and added variables) related to the contact injury risk incidents. The tackle parameters were not analysed in the same multivariate regression model as the other variables, as they formed a separate and pre-determined group.[71] As there were only three tackle parameters, a multivariate regression analysis of them was not performed. Comparisons between groups were made using the chi-square test and the level of significance was set at p-values of < 0.05.

Intra-observer reliability was tested, by reviewing and re-analysing 10% of the contact injury risk incidents a second time. At least three weeks were allowed between the first and the second assessment, in order to reduce potential learning bias. The reviewed and re-analysed contact injury risk incidents were randomly chosen, from the three tournaments, and included a re-analysis of 23 different teams. The agreement between the two sets of results was determined by the kappa statistic (κ). The level of agreement was defined as follows: poor with κ=0.20; fair with κ=0.21 to 0.40; moderate with κ=0.41 to 0.60; substantial with κ=0.61 to 0.80 and very good with κ>0.80.[190]

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

RESULTS

4

4.1 Significant association between injury incidence and the current score in the match

In all, 441 match-play injuries were reported within the injury-surveillance system, during the three FIFA World Cup tournaments, giving a total injury incidence of 67.8/1,000 match hours (95%CI 61.7/1,000 match hours to 74.5/1,000 match hours). On 415 (94.1%) injury report forms, the minute of injury was reported and the score at the moment of injury could therefore be assessed. There was significant variation in the injury incidence between the different groups, based on the current score in the match (p=0.026). With regard to the different score groups, the highest injury incidence was calculated during match periods when the score was even (the two teams were drawing) but goals had been scored, followed by match periods with a goal difference of two or more goals between the two teams and match periods when there was a one-goal difference between the teams. The lowest injury incidence was calculated during

Table 2. Incidence of injury based on the current score in the match.

	Number of injuries	Exposure hours	Incidence (95% CI)	IRR (95% CI)	p-value
0-0	150	2736	54.8 (46.4-64.3)	1.00 (Reference)	
Even	51	628	81.2 (60.5-106.8)	1.48 (1.08-2.04)	0.015
1-goal difference	149	2310	64.5 (54.5-75.7)	1.18 (0.94-1.48)	0.16
≥ 2-goal difference	65	826	78.7 (60.7-100.3)	1.43 (1.07-1.92)	0.016

match periods with the initial 0-0 score, i.e. when teams were drawing and no goals had yet been scored. Table 2 shows the incidences for the four groups based on the current score in the match, as well as their incidence rate ratios (IRRs), in relation to the initial 0-0 score that was used as the reference value.

4.2 Injury incidences different for drawing, losing and winning teams

There were significant differences in the injury incidence between drawing, losing and winning teams (p=0.008). Teams currently winning had the highest injury incidence (81.0/1,000 match hours (95%CI 67.5/1,000 match hours to 96.4/1,000 match hours), followed by teams currently drawing, for which an incidence of 59.7/1,000 match hours (95%CI 51.8/1,000 match hours to 68.6/1000 match hours) was calculated. The difference in injury incidence between the drawing and winning teams was statistically significant (p=0.007). The teams currently losing had the lowest injury incidence of 55.5/1,000 match hours (95%CI 44.4/1,000 match hours to 68.4/1,000 match hours). Table 3 shows the injury incidences separately for drawing (reference value), losing and winning teams, as well as their relative incidence rate ratios (IRRs).

Table 3. Incidence of injury for drawing, losing and winning teams.

	Number of injuries	Exposure hours	Incidence (95% CI)	IRR (95% CI)	p-value
Drawing	200	3364	59.7 (51.8-68.6)	1.00 (Reference)	
Losing	87	1568	55.5 (44.4-68.4)	0.93 (0.72-1.19)	0.56
Winning	127	1568	81.0 (67.5-96.4)	1.36 (1.09-1.69)	0.007

4.3 The association between PGDIs and injury incidence

The injury incidence was significantly higher (p<0.001) during match periods at the minutes of PGDIs or within the following five minutes, than during other match periods: 76.7/1,000 match hours (95% CI 66.6/1,000 match hours to 87.9/1,000 match hours) vs. 54.0/1,000 match hours (95% CI 46.9/1,000 match hours to 61.9/1,000 match hours). The match exposures, for the two match periods respectively, were 2,686 and 3,815 player hours.

The most frequent PGDI during matches was a yellow card, followed by goals, injuries and, ultimately, red cards. On average, 4.6 (SD 2.6) yellow cards were shown by the referee during a match, while the numbers of other PGDIs per match were 2.5 (SD 1.6) for goals, 2.3 (SD 1.7) for injuries and 0.3 (SD 0.6) for red cards. In all, there were an average of 9.5 (SD 3.8) PGDIs per match.

The lower part of Figure 1 shows the variation in injury incidence between consecutive 15-minute periods of matches. The variation between these match periods was statistically significant (p<0.001). Of the 15-minute match periods, the highest injury incidence was calculated for the last 15-minute periods of the first half – 90/1,000 match hours (95% CI 72.8/1,000 match hours to 110/1,000 match hours), while the lowest injury incidence of 33.1/1,000 match hours (95% CI 23.1/1,000 match hours to 46.1/1,000 match hours) was calculated for the initial 15-minute match periods of the matches.

The upper part of Figure 1 shows the mean frequencies of yellow cards, red cards and goals (PGDIs with injuries excluded) during the consecutive 15-minute match periods and demonstrates the relationship between injury incidence (lower part of Figure 1) and PGDIs. The association between PGDIs other than injuries and injury incidence was significant: there was a risk ratio of 1.17 (95%CI 1.08 to 1.26) for an injury per PGDI other than injury (p<0.001). The risk ratio was 1.15 (95% CI 1.06-1.24), after adjusting for the match period, which was still significant (p<0.001).

4.4 Differences in injury incidence between the playing positions

The injury incidence varied significantly between defenders, midfielders, forwards and goalkeepers (p<0.001), when assuming a hypothetical 1:4:4:2 formation (one goalkeeper, four defenders, four midfielders and two forwards). The highest injury incidence of 85.5/1,000 match,hours (95% CI 69.8/1,000 match hours to 104.2/1,000 match hours) was calculated for forwards. Defenders had the second highest injury incidence of 68.8/1,000 match hours (95% CI 58.6/1,000 match hours to 80.2/1,000 match hours). The injury incidence for midfielders was 59.0/1,000 match hours (95% CI 49.6/1,000 match hours to 69.7/1,000 match hours) and was thus the lowest injury incidence calculated for the outfield playing positions. Goalkeepers had the lowest injury incidence of all playing positions (35.6/1,000 match hours (95% CI 22.1/1,000 match hours to 54.5/1,000 match hours)). The injury incidences for the playing positions and their incidence rate ratios (IRRs) are presented in Table 4.

The interaction between playing position and teams' drawing/losing/winning status was statistically significant (p<0.001). However, the assessment of

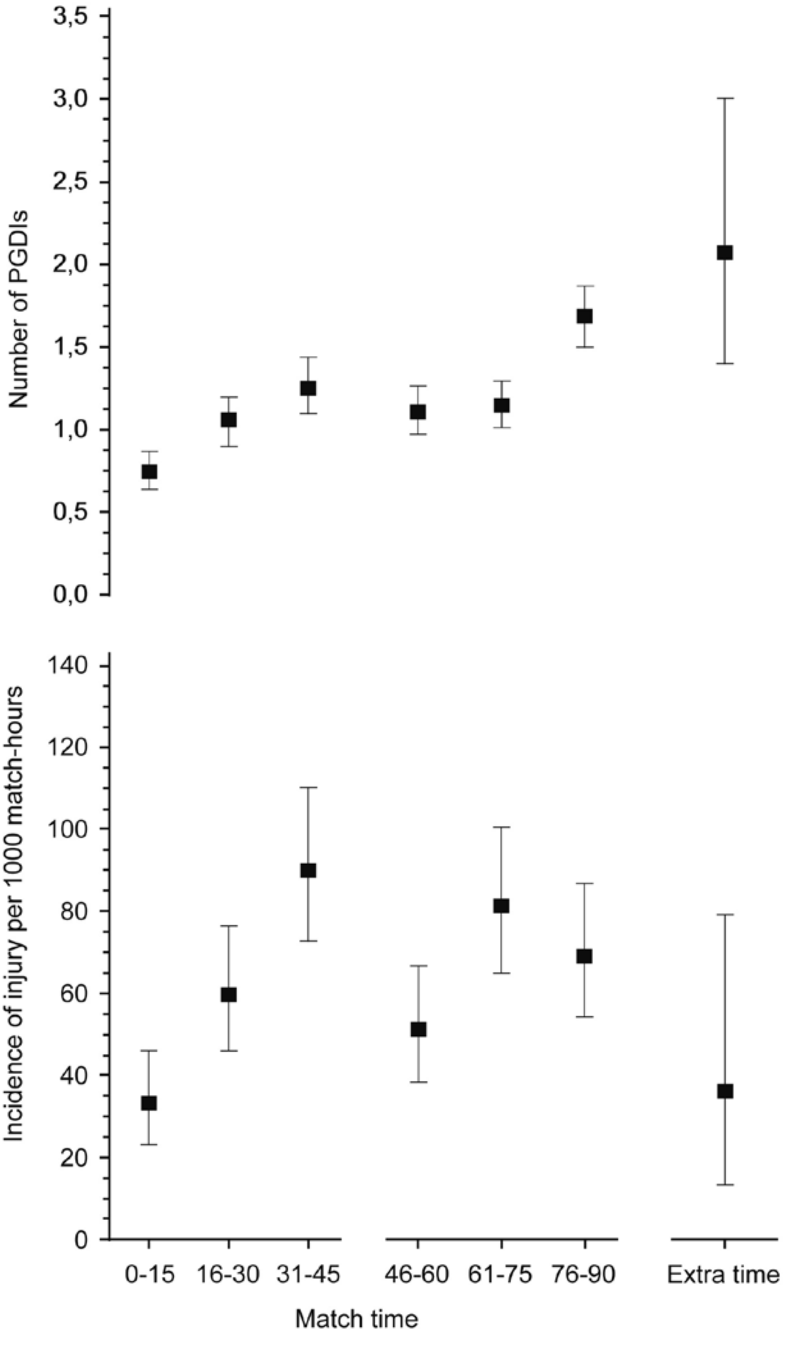

Figure 1. General injury incidence and number of PGDIs (injuries excluded) during consecutive 15-minute match periods. Ryynänen et al. Published in British Journal of Sports Medicine 2013; 47(15): 970-973.

Table 4. Injury incidences for the different playing positions

	Number of injuries	Exposure hours	Incidence (95% CI)	IRR (95% CI)	p-value
Defenders	162	2356	68.8 (58.6-80.2)	1.00 (Reference)	
Midfielders	139	2356	59.0 (49.6-69.7)	0.86 (0.68-1.08)	0.18
Forwards	101	1178	85.7 (69.8-104.2)	1.25 (0.97-1.60)	0.082
Goalkeepers	21	589	35.6 (22.1-54.5)	0.52 (0.33-0.82)	0.005

the relationship between injury incidence for the different playing positions and the drawing/losing/winning status of the team revealed that the forwards had a tendency towards a lower injury incidence when their team was winning, while the opposite trend was observed for defenders and midfielders. The injury incidences for the outfield playing positions for drawing, losing and winning teams are shown in Figure 2.

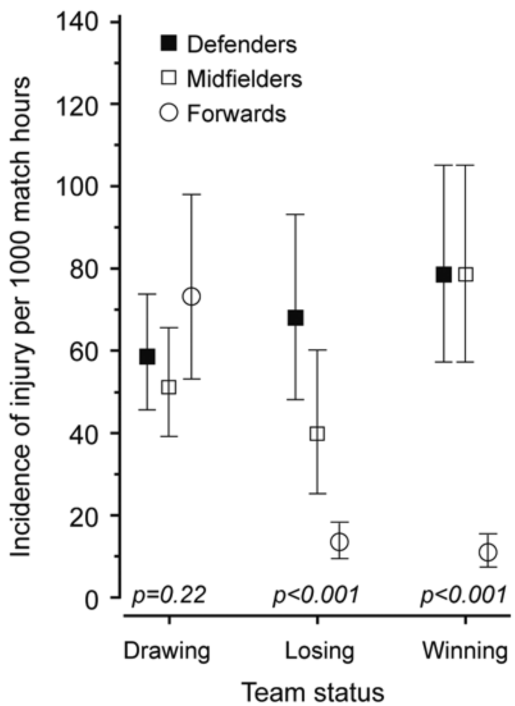

Figure 2. Injury incidences for outfield playing positions in drawing, losing and winning teams. Ryynänen et al. Published in British Journal of Sports Medicine 2013; 47(15): 960-964.

4.5 The relationship between recovery time and injury incidence

Figure 3 demonstrates the association between injury incidence and teams' recovery time between matches (expressed as the number of full days of recovery). Teams had between two and five recovery days between matches, between the second round of group stage matches and the final match. There was a linear relationship between an ascending number of recovery days and a higher injury incidence (p=0.043). The highest injury incidence of 85.9/1,000 match hours (95% CI 66.9/1,000 match hours to 108.8/1,000 match hours) was calculated for teams playing after five full recovery days, followed by teams playing after four full days of recovery (66.8/1,000/match hours (95%CI 56.5/1,000 match hours to 78.4/1,000 match hours)), and teams playing after three full days of recovery (63.1/1,000 match hours (95%CI 51.4/1,000 match hours to 76.8/1,000 match hours)). The lowest i jury incidence of 54.9/1,000 match hours (95% CI 31.4/1,000 match hours to 89.1/1,000 match hours) was calculated for teams playing after only two full recovery days.

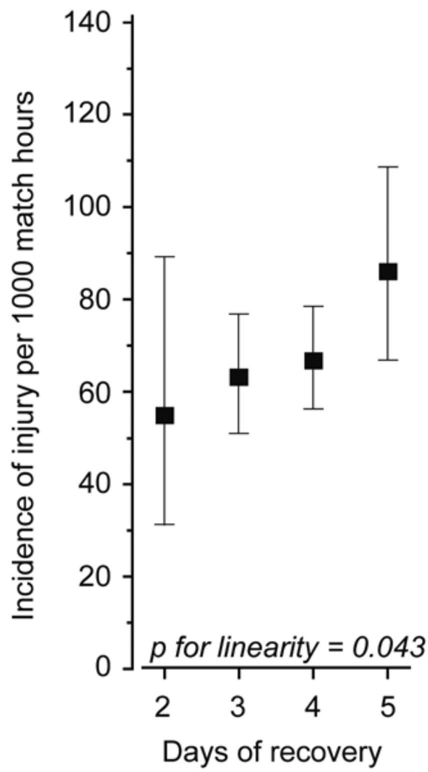

Figure 3. Injury incidence increased with an increasing number of recovery days. Ryynänen et al. Published in British Journal of Sports Medicine 2013; 47(15): 960-964.

4.6 Comparison of foul play injuries and non-foul play injuries

For 412 injuries (93%), the cause of injury, with respect to the possible involvement of foul play, was reported on the injury report forms and these injuries were included in the analyses. One hundred and thirty-four of these injuries (30% of all injuries) were caused by foul play, as judged by the team physician and/or the injured player, and 278 injuries did not involve a foul. The incidence of foul play injuries was 20.6/1,000 match hours (95%CI 17.3/1,000 match hours to 24.4/1,000 match hours), which was significantly lower ($p<0.001$) than the injury incidence of non-foul play injuries, which was 42.6/1,000 match hours (95%CI 37.7/1,000 match hours to 47.9/1,000 match hours).

For all (apart from one) injuries included in the analyses, the mechanism of injury (possible involvement of player-to-player contact) was reported on the injury

Table 5. Injury locations for foul play injuries and non-foul play injuries

Injured body part	Number of injuries (%) Foul play	Number of injuries (%) Non-foul
Lower leg	38 (28.4)	36 (12.9)
Ankle	30 (22.4)	30 (10.8)
Thigh	16 (11.9)	68 (24.5)
Head/face	14 (10.4)	30 (10.8)
Knee	12 (9.0)	33 (11.9)
Trunk	8 (6.0)	20 (7.2)
Foot/toe	7 (5.2)	18 (6.5)
Shoulder	5 (3.7)	7 (2.5)
Upper extremity	3 (2.2)	12 (4.3)
Achilles tendon	1 (0.7)	1 (0.4)
Groin	0	17 (6.1)
Hip	0	6 (2.2)

report forms. All 134 foul play injuries and 152 of the total of 278 non-foul play injuries (54.7%) were caused by contact between players. One hundred and twenty-five non-foul play injuries (45%) were caused by non-contact mechanisms.

Table 5 presents the injury locations, with their relative proportions of foul play injuries and non-foul play injuries separately. The lower leg and the ankle were the most common locations of foul play injuries, with 28.4% and 22.4% respectively of all foul play injuries affecting these body parts. The lower leg and the ankle were significantly more common locations for foul play injuries than for non-foul play injuries ($p<0.001$ and $p=0.002$). The most commonly injured body parts for non-foul play injuries were the thigh (24.5%) and the lower leg (12.9%). Thigh injuries were significantly more common non-foul play injuries, compared with foul play injuries ($p<0.01$). In addition, injuries to the groin, which constituted 6.1% of the non-foul injuries, while none of the foul play injuries affected the groin,

Table 6. Types of foul play injury and non-foul play injury

Type of injury **Number of injuries**	**Number of injuries (%)** *Foul*	**Number of injuries (%)** *Non-foul*
Contusion	91 (67.9)	105 (37.8)
Ligament sprain	21 (15.7)	33 (11.9)
Laceration/abrasion/skin lesion	7 (5.2)	18 (6.5)
Muscle strain/rupture/tear	5 (3.7)	69 (24.8)
Concussion	3 (2.2)	3 (1.1)
Bone fracture	3 (2.2)	5 (1.8)
Ligament rupture	1 (0.7)	6 (2.2)
Other bone injuries	1 (0.7)	0
Other	1 (0.7)	19 (6.8)
Muscle cramps	0	10 (3.6)
Tendinosis/tendinopathy	0	3 (1.1)
Lesion of the meniscus	0	3 (1.1)
Arthritis/synovitis/bursitis	0	2 (0.7)
Fasciitis/aponeurosis	0	1 (0.4)

were significantly more common non-foul play injuries compared with foul play injuries (p<0.01).

With the exception of one foul play injury and one non-foul play injury, the injury type was reported on all injury report forms included in the analyses. The most common injury type, in terms of both foul play injuries and non-foul play injuries, was contusion. However, contusions were a significantly more common injury type for foul play injuries, compared with non-foul play injuries (p<0.001). Muscle strains, ruptures or tears were the second

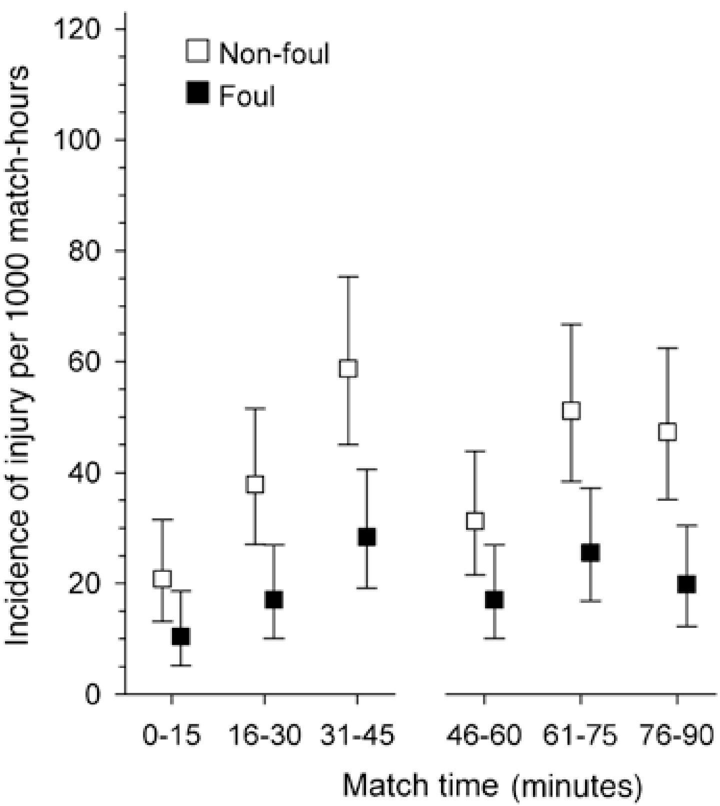

Figure 4. The incidences of foul play injuries and non-foul play injuries during different match periods. Ryynänen et al. Published in British Journal of Sports Medicine 2013; 47(15): 986-991.

Table 7. Severity of foul play and non-foul play injuries

Severity (estimated days of absence)	Number of injuries (%) *Foul play*	Number of injuries (%) *Non-foul*
Slight (0)	52 (40.9)	74 (29.1)
Minimal (1-3)	51 (40.2)	102 (40.2)
Mild (4-7)	12 (9.4)	38 (15.0)
Moderate (8-28)	9 (7.1)	31 (12.2)
Severe (over 28)	3 (2.4)	9 (3.5)

most common type of non-foul play injuries and constituted 24.8% of all non-foul play injuries. The corresponding percentage of muscle strains, ruptures or tears for foul play injuries was 3.7% and this injury type was significantly more common for non-foul play injuries compared with foul play injuries ($p<0.001$). Table 6 presents the types of injury in terms of both foul play injuries and non-foul play injuries.

For 94.8% (n=127) of all foul play injuries and for 91.4% (n=254) of all non-foul play injuries, an assessment of the severity of injury was reported on the injury report form by the team physician. The mean lay-off time, expressed as the resulting number of days of absence from playing or training football, was significantly ($p<0.01$) shorter for foul play injuries compared with non-foul play injuries. The median (IQR) days of absence (lay-off time) resulting from foul-play injuries was one (IQR 0, 3) for foul play injuries and two (IQR 0, 5) for non-foul play injuries. The numbers of injuries, with their relative proportions, within each category of injury severity, ranging from slight to severe, are presented in Table 7.

4.6.1 Comparison of incidences of foul play injuries and non-foul play injuries during different match periods

An analysis of the differences in injury incidence, between foul play injuries and non-foul play injuries, during subsequent 15-minute match periods, revealed a significant main effect of both the cause (foul play vs. non-foul play) and the match period on injury incidence during matches ($p<0.001$ and $p<0.001$). No significant interaction between the cause of injury and match time was observed ($p=0.99$). Moreover, the analysis of differences in injury incidence, between foul play injuries and non-foul play injuries, depending on teams' current losing/drawing/winning status during the course of matches, showed a significant main effect of both the cause of injury and the team status on injury incidence ($p<0.001$ and $p=0.01$ respectively). No interaction between the cause of injury (foul vs. non-foul) and teams' current losing/drawing/winning status was observed ($p=0.34$). Figures 4 and 6 present the injury incidences of both foul play injuries and

Table 8. Incidences (per 1,000 match hours) of foul play injuries and non-foul play injuries for the different playing positions.

Playing position	Foul play injury incidence (95%CI)	Non-foul play injury incidence (95%CI)	p-value
Forwards	26.2 (17.8 to 37.2)	53.2 (41 to 68.2)	<0.01
Midfielders	21.6 (16.1 to 28.4)	34.3 (27.2 to 43.6)	<0.05
Defenders	17.3 (12.5 to 23.5)	46.1 (37.9 to 55.6)	<0.001
Goalkeepers	5.1 (95% CI 1.1 to 14.8)	28.8 (16.8 to 46.1)	<0.01

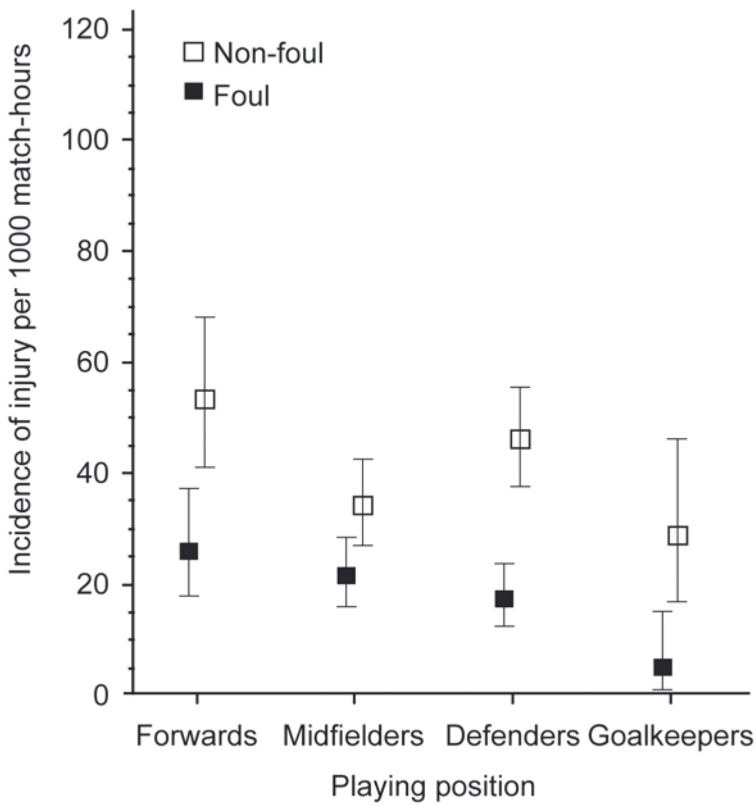

Figure 5. The incidences of foul play injuries and non-foul play injuries for the different playing positions. Ryynänen et al. Published in British Journal of Sports Medicine 2013; 47(15): 986-991.

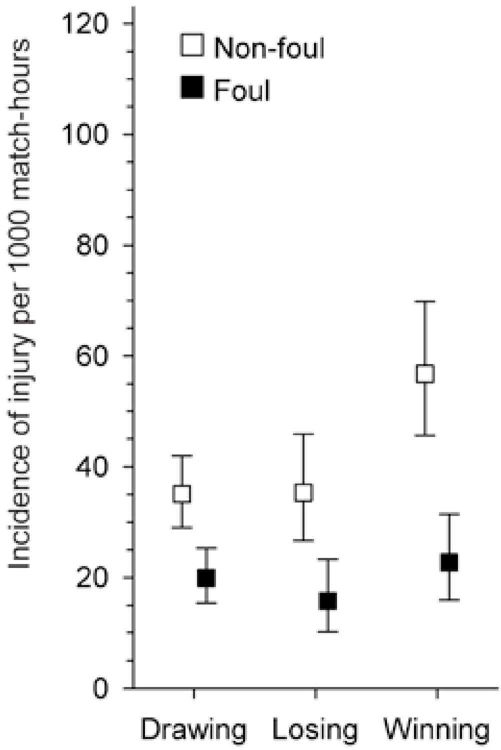

Figure 6. The incidences of foul play injuries and non-foul play injuries for drawing, losing and winning teams. Ryynänen et al. Published in British Journal of Sports Medicine 2013; 47(15): 986-991.

non-foul play injuries during subsequent 15-minute match periods and depending on the teams' drawing/losing/winning status respectively.

4.6.2 Comparison of injury incidences, for foul play injuries and non-foul play injuries, between playing positions

An analysis of the differences between foul play injury incidences and non-foul play injury incidences for the different playing positions revealed no significant interaction between the cause of injury (foul play vs. non-foul play) and playing position (p=0.085). When it came to the incidences of foul play injuries and non-foul play injuries in general, the incidences of foul play injuries and non-foul play injuries differed significantly for all playing positions, with the incidence of non-foul play injuries being significantly higher for all positions (Table 8 and Figure 5).

4.6.3 The association between the number of fouls and injuries in a match

A total of 6,678 fouls were committed (as judged by the match referees) during the 192 matches played in the three World Cup tournaments. The total numbers of fouls for each tournament separately were 2,300 in the 2002 World Cup, 2,367 in the 2006 World Cup and 2,011 in the 2010 World Cup.

In all matches played, the number of fouls per match varied between 13 and 62 and an average of 35 fouls were committed per match (SD 1.7). A significant association between the total number of fouls per match and the total number of injuries was observed (p<0.001), with the injury incidence in matches showing an increasing trend with an increasing total number of fouls per match, as presented in Figure 7. The number of matches in each match category, based on the number of injuries per match, are presented in Table 9.

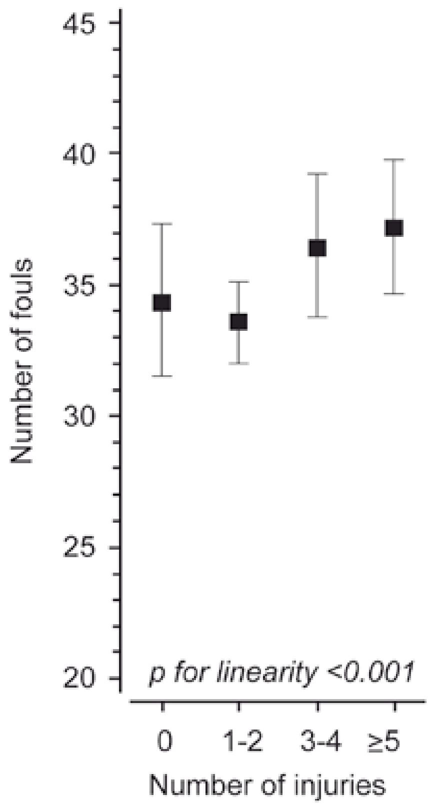

Figure 7. The relationship between the numbers of fouls and injuries in matches.
Ryynänen et al. Published in British Journal of Sports Medicine 2013; 47(15): 986-991.

Table 9. The number of matches within match categories based on the total number of fouls.

Number of injuries	Number of matches
0 injuries	22
1-2 injuries	101
3-4 injuries	46
5 or more injuries	23

4.7 Results of the video analysis

The revision of full video recordings of the 192 matches played resulted in the identification of a total of 671 contact injury risk incidents. Of the 441 injuries reported in the injury-surveillance system from the three World Cup tournaments, 304 (68.9%) were contact injuries. One hundred and twenty-eight (42.1%) of the contact injuries reported in the injury-surveillance system could be linked to a contact injury risk incident, identified from the video recordings. The intra-rater reliability of the video analysis of contact injury risk incidents was very good (κ=0.88-0.98) for all variables and tackle parameters. Table 10 summarises the study results for the FIA variables and the added variables, as well as the results of the regression analysis.

4.7.1 Regression analysis of FIA (and added) variables

Two of the variables included in the regression analysis were identified as independent predictors of injury. In other words, there were significant differences between the ratios of contact injury risk incidents that could be linked to post-match injury reports and contact injury risk incidents that could not be linked to post-match injury reports. These two variables were:

- Attack type ($p<0.01$)
- The involvement of foul play ($p<0.05$)

"Long (organised) attacks" was the variable category for the variable "attack type", which had the lowest ratio (11.6%) of contact injury risk incidents that could be linked to post-match injury reports, per contact injury risk incidents within the variable category. The ratio was highest for "long attacks including a long pass" (27.7%), followed by "set plays" (24.2%) and "breakdown attacks" (23.3%).

When the contact injury risk incidents involved foul play, as judged by the match referee, the ratio (17.1%) of contact injury risk incidents that could be linked to post-match injury reports, per contact injury risk incidents within the variable category, was lower than for contact injury risk incidents that did not involve foul play (22.4%). None of the other variables was identified as an independent predictor of injury.

Table 10. The numbers of both the contact injury risk incidents that could not be linked to an injury and those that were linked to an injury, as well as their relative proportions for all the categories of each variable. In addition, the table shows the results of the multivariate regression analysis, with the relative risk (OR) for each category, as well as the significance of differences in the relative risks between the categories of each variable.*

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

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

4.7.2 Results of the tackle analysis

Six hundred and nineteen of the 671 contact injury risk incidents (92.1%) involved a tackle, as defined in the methodology proposed by Fuller et al.[71] One hundred and nineteen of the contact injury risk incidents that involved a tackle (19.2%; 95%CI 16.1-22.3) could be linked to post-match injury-surveillance reports.

Figure 8 presents the percentages of contact injury risk incidents involving a tackle that could be linked to injuries (as defined in the FIFA post-match injury surveillance) for the tackle parameters direction, mode and action.

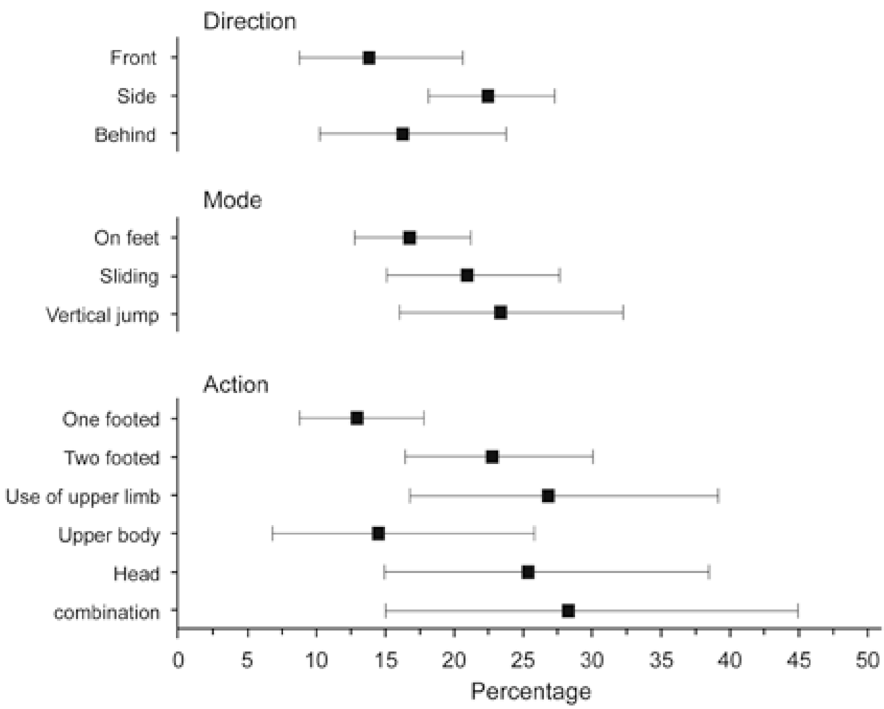

Figure 8. The percentages and 95% confidence intervals of contact injury risk incidents involving a tackle that could be linked to injury for the different tackle parameters and categories. Ryynänen et al. Published in Global Journal of Medical Research (H) 2014; 14(3): 1-9.

Tackle action

For the categories in the "tackle action" parameter, the differences in the proportions of contact injury risk incidents involving a tackle that could be linked to injuries and other contact injury risk incidents involving a tackle were statistically significant (p=0.013, lower part of Figure 8). "*Two-footed*" tackle actions and tackle actions involving "*use of upper limb*", a "*clash of heads*" or a "*combination*" of several tackle actions were more frequently associated with injuries than tackle actions involving "*upper body contact*" or "*one-footed*" tackle action.

Most tackles that resulted in an identifiable contact injury risk incident involved a "*one-footed*" tackle action (n=234). The second most common tackle action was "*two footed*", with 158 contact injury risk incidents resulting from tackles with this action. "*Two-footed*" tackles were followed by tackles involving "*use of upper limb*", tackles involving "*upper body contact*", tackles involving a "*clash of heads*" and, ultimately, tackles for which a combination of several tackle actions with the potential to cause injuries was observed ("*combination*", n=39) and no dominant tackle action could therefore be determined.

Tackle direction and mode

With respect to the categories in the "tackle direction" and "tackle mode" parameters, there were no statistically significant differences in the proportions of contact injury risk incidents involving a tackle that could be linked to injuries, compared with other contact injury risk incidents involving a tackle. Most contact injury risk incidents resulted from tackles from the "*side*" (n=346), 144 tackles came from the "*front*", while 129 of the tackles resulting in contact injury risk incidents came from "*behind*". The most common "tackle mode" category, resulting in contact injury risk incidents, was "*on feet*" (n=328). One hundred and seventy-six tackles had the mode "*sliding in*" and 115 a "*vertical jump*".

DISCUSSION

The most important findings in the present thesis are that game-related changes are associated with injury incidence in male World Cup football and that certain match events may affect the variation in injury incidence during a match. The thesis also identified some concerns in terms of the widely used video analysis methodologies, including information that may serve as a base for developing improved research tools. Finally, the results of this thesis show that match statistics can be successfully combined with injury-surveillance data, adding to the current understanding of factors associated with football injuries.

5.1 Why did changes in the score affect the injury incidence?

The present thesis showed that there was significant variation in the injury incidence during a match, partly dependent on the current score. There were significant differences in injury incidence not only depending on the teams' current drawing/losing/winning status but also for both teams depending on the score in the match.

The association between the current score and injury incidence has, to the best of our knowledge, not previously been studied in football, or any other sports.

The injury incidence was lowest during the 0-0 score, which is also the initial score at the beginning of the match. Significantly higher injury incidences were found when the score was even, but goals had been scored (p=0.015), and during match periods, when there was a two or more goal difference between the teams facing each other (p=0.016). As the 0-0 score is the initial score in the match, it is difficult to determine the differences between the impact of fatigue (or other time-related factors) and the impact of the current score on the changes in injury incidence. Many previous studies have shown that the incidence of injury is lowest during the first fifteen minutes of the halves of the match and that the incidence tends to increase substantially as the match proceeds, a phenomenon often attributed to fatigue.[53, 56, 57, 133] Physiological studies of football indicate that sprinting and high-intensity running, match intensity and distances covered decrease during the second half of the match, compared with the first half.[10, 12, 13, 21, 22, 26, 154] However, even though fatigue appears to be a contributory factor, the association between fatigue and injury incidence has not been undoubtedly proven. The fact that the 0-0 score represents the score during the initial moments of the match was most probably not the only reason for the lowest injury incidence during that period found in the present study. Moreover, player exposure was highest for the 0-0 score group, showing that a score of 0-0 is not limited only to the first minutes of a match. Moreover, in 68 (of 192) matches in the present material, the first goal was not scored before the second half and, in 13 matches in the present material, 0-0 was the final score in the match.

There were also significant differences in the injury incidence (p=0.008) between match periods, depending on the teams' current drawing/losing/winning status. While there was no statistically significant difference between the incidence of injury for drawing (reference value) and losing teams (p=0.56), the incidence of injury for winning teams was significantly higher (p=0.007). The end result of a match, and its association with injury incidence, has been studied before. Hägglund et al.[111] found no differences in injury incidence between matches with different outcomes (won, drawn, lost) in European Championship football. On the other hand, in a study at national team level, Ekstrand et al.[191] found that the injury incidence was higher during matches where the team had lost. The final score might, however, not reflect the score during the match, as goals can be scored until the last minutes of the match. While these results from previous research might appear contradictory, considering the findings in the present thesis, the present studies focused on the current score and, for this reason, the results of the present thesis are not directly comparable to the previous results.

Although the underlying factors for the score-dependent variation in injury incidence cannot be identified, based on the results of the present thesis, some underlying reasons for the phenomenon can be speculated upon. As the FIFA World Cup is a prestigious tournament, with a relatively small number of matches played only once every four years, the importance of the result of a single match for a team must be emphasised. When a team scores a crucial goal, and takes the lead, this could provoke a reaction in the other team as it then runs an increased risk of losing the match. Aoki et al.[192] conducted a study of professional Japanese football players and discussed the possibility of player attitudes affecting the variation in injury incidence during different match periods. The higher injury incidence for the team in the lead could be partly explained by possible changes in team strategy that the leading team may apply in order to maintain its lead. By applying a more defensive strategy, for example, in order to prevent the opponent from scoring. On the other hand, the losing team might have to make strategic changes as well, such as applying a more aggressive style of play, in order to equalise the score. Supporting the association between the current match result and team tactics, an analysis of ball possession strategies in top-level Spanish male football, by Lago-Peñas and Dellal,[193] showed that team strategies were affected by the score line. They found that teams that were losing significantly increased their ball possession, while the opposite was found for winning teams.[193]

Furthermore, Junge et al.[116] found that 90% of footballers are ready to commit a deliberate (or "professional") foul if required, depending on the score and importance of the match. Any match in a FIFA World Cup could arguably be regarded as being of great importance. Moreover, Rascle et al.[157] found differences in soccer players' perceived legitimacy of aggression, partly dependent on the current score. Further support was found in a study by Fuller,[156] which showed that the level of injury in World Cup football caused by the weaker teams (teams that were eliminated at the group stage) was greater than that caused by the stronger teams, suggesting that weaker teams may, indeed, play more aggressively. Based on the results, Fuller concluded that some injuries in football were likely to be caused by deliberately aggressive behaviour on the part of certain players.[156] On the other hand, a study of professional ice hockey players did not find any association between the aggressive behaviour of players, depending on the winning/drawing/losing status of the team.[194] In football, the percentage of tackles involving foul play does not appear to differ between winning, drawing and losing teams.[156] However, a foul/tackle ratio might depend on various other factors not related to aggression. These situation-dependent changes in player attitudes and team strategies present some possible underlying reasons for the score-dependent variation in injury incidence during matches.

5.2 PGDIs CONTRIBUTE TO THE VARIATION IN INJURY INCIDENCE DURING MATCHES

Study II showed that yellow and red cards, injuries and goals are related to changes in injury incidence during a match. These essential, and partly inevitable, match events have not previously been studied as extrinsic risk factors for injuries. As was discussed in the previous paragraph, changes in the score might provoke responses, such as aggression, in players and teams that influence the risk of injuries during the following course of the match. According to the hypothesis, yellow and red cards, or injuries may also have a similar influence. The results of Study II support this hypothesis.

Psychological stressors and situation-dependent emotional states appear to be associated with the risk of suffering sports injuries.[155] A study assessing the effect of behavioural and situational factors on concentration and skill performance in sports suggested that concentration is negatively affected by aroused, angry behaviour and by a social environmental setting of considerable complexity and stress.[195] Seeing a team-mate or another player getting injured might represent a situation of considerable stress. Consequently, it could affect the player's concentration, and emotional state and even lead to physiological responses. Stanger et al.[196] found greater physiological responses (blink responses, heart-rate deceleration, as well as P300 waves and slow-wave potentials on EEG) when athletes were looking at unpleasant sport-specific pictures (players being hurt by another player or players being badly injured), compared with neutral or pleasant pictures. The participants in the study by Stanger et al.[196] were both male and female football, rugby and field-hockey players. An injury that leads to a player being substituted could also affect the team strategy, especially if the injury affects a key player. For this reason, there may be consequences of injuries that lead to changes in team tactics, some of which may lead to an increased risk of injury. Previous research has shown that team performance in general is negatively affected by injuries.[62] The results of the present thesis suggest that the association between injuries and the match result is reciprocal.

As described in the methods section, yellow and red cards are sanctions by the referee which can result from various offences, such as unsporting behaviour, dissent in the form of word or action, persistent infringement of the laws of the game, delaying the restart of play, serious foul play, violent conduct, spitting at another player/or any other person, or denying an obvious goal-scoring opportunity by foul play, among others.[9] These offences include many that could potentially affect the players' situation-dependent emotional states. These sanctions may also reflect aroused and angry behaviour in a social environmental setting of complexity and stress, that has been shown negatively to affect the players' concentration.[195] Moreover, foul play, and especially fouls resulting in severe sanctions, may provoke aggression and in the worst cases even actions involving elements of revenge among the team-mates of the player on whom the foul is committed. Contact between players accounts for the majority (63-86%) of the injuries in international football tournaments [50-53, 111] and the deliberately aggressive behaviour of players is probably a contributory factor in injury causation.[156] A red card, which leads to the expulsion of the offending player, may also disrupt the balance between the two teams, as the team of the sent-off player consequently has to play with one fewer player. This might lead to fatigue in the players in the outnumbered team, as they have to compensate for the absence of one of their players.

As discussed previously in terms of the variation in injury incidence during a match, the total incidence of injury (without taking account of injury- or player-specific factors) increases towards the end of each half and this has generally been attributed to increasing player fatigue, which does appear to play an essential role.[55, 83, 192] As also discussed in the introductory section of the present thesis, previous research has produced somewhat contradictory findings relating to the injury incidence variation during a match. Research on the physiological aspects of football indicates that the amounts of high-intensity running and distance covered by sprinting are similar in the last 15 minutes of the first half and the first 15 minutes of the second half,[12] which appears somewhat contradictory in terms of the fatigue hypothesis, when it comes to the variation in injury incidence. In the present data, the highest injury incidence during matches was calculated during the last 15 minutes of the first half. There was also a tendency for the injury incidence to decrease during the last 15 minutes of the match (Figure 1). A study of football physiology indicates that this is the match period in which fatigue supposedly accumulates.[12] The degree of the developing fatigue is also affected by match conditions, such as the match result, quality of opposition, among others,[27] suggesting that fatigue and match events could possibly synergistically influence the risk of injury. It appears clear that the variation in injury incidence during a match is multifactorial and many underlying factors probably remain to be discovered.

In Study I, we showed that changes in the score are associated with the variation in injury incidence during a match. The results of Study II show that the injury incidence during a match increased with every PGDI (injuries excluded) and that there was a significant association between the occurrence of PGDIs and injuries. The injury incidence was also significantly higher during short match periods immediately following PGDIs. Curiously, even though the frequency of PGDIs increased steadily towards the end of the match, the injury incidence showed a decreasing trend during the last fifteen minutes of the match. Considering the substantial proportion of injuries caused by contact between players in World Cup football, the accumulating fatigue and the decrease in high-intensity running towards the end of the match [12] could subsequently reduce the potential trauma energy and thus counter-intuitively reduce the incidence of contact injuries.

5.3 The influence of playing position on injury incidence

The present thesis found that the incidences between the playing positions differed significantly ($p<0.001$), with forwards having a substantially higher injury incidence than players in other positions. Previous research has produced contradictory results regarding possible differences in injury incidence between playing positions. Some studies have shown no significant differences,[60, 67] while others have indicated an increased risk for defenders [66] and yet others have suggested that forwards might run the greatest risk.[130, 197] The previous studies have used different methodologies, making it difficult to compare the results.

The reasons for the higher risk of injury for forwards remain unclear. One possible explanation is the nature of the tournament. The small number of matches played in a World Cup tournament highlights the importance of the result of each match, speculatively emphasising the pressure on forwards to score goals. The underlying reasons may also be related to the different physiological profiles for different playing positions. Several studies of the physiological aspects of top-level football indicate significant differences in physical performances between playing positions.[10, 13, 14, 21, 23] For example, midfielders, the group with the lowest injury incidence in the present data, cover greater distances during matches than other playing positions.[10, 14, 24] This appears somewhat contradictory, as we could thus expect midfielders also to be more prone to fatigue and consequently more prone to injuries. However, the intensity and number of match activities appear to be important for development of fatigue.[20] Bloomfield et al.[14] analysed the physical demands of different playing positions in English FA Premier League football and found that forwards were most subjected to physical contact during high-intensity activities. Power and speed have been shown to be important abilities for players in goal-scoring situations.[19] As physical contact between players is involved in most injuries in World Cup football, the possibly higher trauma energies, due to the high-intensity action at the moment of contact, could be one logical explanation for the high injury incidence found in forwards, in the present thesis. As a result of the position-dependent physical demands, midfielders and forwards may also have different muscle properties, partly explaining the differences in their physical performances, in terms of the level of intensity during match activities.

One of the most interesting findings in the present thesis, in terms of the injury risk for different playing positions, was that the outfield playing positions had different injury incidences, depending on the teams' drawing/losing/winning status. For defenders and midfielders, the injury incidence was highest when their team was winning. This could in part be a result of their role in defending the lead, which might emphasise the importance of their positional role, especially for defenders. Forwards had a substantially higher incidence when their team was drawing, compared with game periods when their team was losing or winning. It could be speculated that forwards are under greater pressure to score, when their team is drawing, compared with game periods when their team is already winning. However, the supposition that forwards in a winning team ran a higher risk of injuries than forwards in a currently losing team appears counter-intuitive, as it could be expected that emphasising the role of forwards in a losing team would be of great importance. Theoretically assuming that the technically and/or tactically superior team is more likely to be leading a match, a speculative explanation could be that the forwards in the losing team may have fewer opportunities to influence the course of the match and therefore be less prone to contact injuries. A study by Di Mascio et al.[23] showed that there is substantial variation in high-intensity running, the work/rest ratios and average distances covered by high-intensity running during different match periods and that these differences are dependent on the positional role of the player. Moreover, as stated above, the degree of the developing fatigue is also influenced by the match result and the quality of the opposition.[27] These physiological alterations, which are dependent in part on positional roles and the current score, present as an underlying factor for these partly surprising results in the present thesis.

5.4 The counter-intuitive association between a longer recovery time and a higher injury incidence

The present thesis found a surprising association between an increasing number of recovery days between matches and an increasing injury incidence. The match schedule during a FIFA World Cup is intense and teams may only have two full days to recover between matches at some stages of the tournament. Considering the literature, this finding appears highly counter-intuitive. Football players have been shown to feel overloaded and often not completely recovered as a result of their match and training schedules.[116] Dupont et al.[198] found that professional top-level players had a significantly higher injury rate when playing two matches a week, compared with periods when the teams played one match a week. Ekstrand et al.[105] showed that 29% of the international players that played more than one match a week for their clubs during the season incurred an injury during the following World Cup, even though these players did not run an increased risk of injury during the intense period of the season. Moreover, muscle injuries have been shown to be significantly associated with condensed match fixtures.[106]

Some possible explanations for the surprising findings in the present thesis can be speculated upon. A study by Mohr et al.[12] suggested that top-level players might adapt to increasing physical demands towards the end of the playing season. The World Cup is played after the end of the club season and it is possible that players have therefore adapted to a high match frequency before the World Cup. This could possibly help to explain why the short recovery time was not associated with a higher injury incidence in the present thesis, compared with a longer recovery time. However, it would not explain the trend towards increasing injury incidence with an increasing recovery time. A methodological aspect relating to the injury definition might offer part of the explanation: in contrast to the present thesis, studies that have associated a condensed schedule with injuries have applied a time-loss definition of injury.[106, 198] Most injuries in male FIFA World Cup football are contusions caused by physical contact between players and a large proportion of World Cup injuries do not result in time loss.[50-52] When players have a longer break between matches, they may have more energy in the following match compared with matches preceded by a short recovery time. The higher energy level may result in more high-intensity activities during a match and thus increase the trauma energies in contact situations, consequently leading to contusions. Almost all time-loss muscle injuries in football have been shown to be the result of non-contact mechanisms.[133] As the contact injuries account for the largest proportion of all injuries, the trend towards increasing injury incidence with increasing recovery time in the present thesis could be accounted for by an increase primarily in these injuries. Unfortunately, the present thesis did not take account of the relative proportions of different injury types and locations in this analysis. Future research should aim to investigate the relationship between recovery time and injuries, with material large enough to assess differences between different injury types.

5.5 Foul play and injuries

The present thesis found that the number of fouls and the number of injuries in a match during FIFA World Cups were significantly associated ($p<0.001$). This is in line with previous research, showing that foul play is involved in the cause of 35-80% of the injuries resulting from physical contact between players [51, 52, 54, 73, 128, 129] and, unsurprisingly, foul play has long been regarded as the most important extrinsic risk factor for injuries.[60] However, even though it has been known that some injuries result from foul play, a relationship between the total number of fouls and injury incidence has not previously been demonstrated.

A foul is called by the match referee when a player breaks the rules and awarding the foul in itself could thus be seen as a preventive measure, encouraging the players to follow the laws of the game. From this perspective, it would appear logical that a large number of fouls awarded by the referee would encourage the players to follow the rules and consequently reduce the number of injuries. However, a large number of fouls in a match reflects the fact that players break the rules frequently and, from this perspective, the higher injury incidence with an increasing number of fouls appears logical. Curiously, prospective injury-surveillance data from World Football Tournaments show that the injuries in female football are increasing, while the number of yellow cards sanctioned by the match referees is decreasing.[54] A tendency towards a high foul frequency at the beginning of a match, resulting in high total foul rates in a match has been shown in the Turkish Football Super League.[199] As stated in the introduction, football players often consider provocation and "hidden" fouls (fouls committed assuming that they will remain unnoticed by the referee) as parts of the game and players often tend to "pay back" the opponent for these fouls.[116] These previous findings may partly explain why fouls accumulate in some matches. Some means for early interventions in matches that start with high foul frequencies, in order to reduce the total number of fouls in a match, may thus be beneficial from an injury-prevention perspective. Strict refereeing with early sanctions could hypothetically encourage the players to follow the rules. This might appear contradictory to other results in the present thesis (Study II), which show that injury incidence is also associated with yellow and red cards and that the incidence of injury is high during short match periods following these sanctions. However, as the results of Study II show, the frequency of PGDIs has a tendency to increase towards the end of the match, with the highest frequencies in the last 15 minutes of the match. As yellow cards were the most frequent PGDIs, this could suggest that few yellow cards are awarded at the beginning of the match, where they might best serve the purpose of reducing the total number of fouls (and consequently also cards) during a match. Fouls may also have effects similar to those of PGDIs on players' concentration, by contributing to an aroused, angry and aggressive environment, and consequently contribute to the increased injury risk during matches.

The question nonetheless remains; to what extent do foul play injuries affect the association between the total number of fouls and injury incidence during matches? Figure 7 shows that the differences in the total number of fouls in match groups based on the total number of injuries per match are not very substantial. It therefore appears possible that foul play injuries accounted for this association to some extent. However, considering that foul play injuries accounted for 30% of all injuries, it is questionable whether they alone could have accounted for the significance of the association. Future studies, with large enough cohorts, should answer this question.

5.6 Foul play injuries were less severe than non-foul play injuries

The present thesis supports the findings in previous studies,[82, 91, 111] indicating that foul play injuries are less severe than non-foul play injuries. In the present data, foul play injuries accounted for a quarter of all the severe injuries and a fifth of all the moderate injuries. The cohort in the present thesis is too small to analyse the clinical significance of these findings. In addition, the post-match injury-surveillance methodology may unfortunately underestimate the incidence of severe injuries,[54] as the injury severity is based on the team physicians' post-match estimation and no follow-up of injuries is included. A speculative reason for the shorter lay-off time resulting from foul play injuries in the present thesis might, again, be the large proportion of contact injuries in the total number of reported injuries. Supporting this, the present thesis found that contusions (mainly to the lower leg and ankle) constituted a larger proportion of foul play injuries, compared with non-foul play injuries, and that the opposite was found for muscle strains/ruptures/tears (mainly to the thigh), which have been shown to occur almost only via non-contact mechanisms.[133] This appears logical, as all foul play injuries in the present data were contact injuries, while almost half the non-foul play injuries did not result from contact between players. This, might therefore reflect the finding that foul play injuries were less severe, as it has been shown that muscle injuries are responsible for more than a quarter of the total injury lay-off for a professional team during a season.[133]

5.7 The incidences of foul play injuries and non-foul play injuries had a similar variation between different match periods and between playing positions

As in many previous studies, the variation in injury incidence was significant between the different 15-minute periods of the match. The variation in injury incidence between the 15-minute periods, as well as the variation depending on the teams' winning/drawing/losing status (Studies I and II) have previously been discussed in this thesis. Curiously, the variation in foul play injury incidence within the different time periods and depending on teams' current winning/drawing/losing status in a match was similar to that of non-foul play injuries. In other words, foul play injury incidence and non-foul play injury incidence appear to peak during the same match periods.

Similarly, the results of the present thesis suggest that none of the positions run a substantially higher relative risk of suffering an injury caused by foul play compared with the other positions. The results of Study III demonstrate that all playing positions had a higher incidence of non-foul play injuries, compared with foul play injuries, and that no interaction was found between foul play injuries and non-foul play injuries, according to playing positions.

Based on the findings in the present thesis, it is difficult to identify match periods during which the incidence of foul play injuries is particularly high, compared with non-foul play injuries. However, the association between the total injury incidence and the total number of fouls during a match suggests that a large number of fouls affects the incidence of both contact and non-contact injuries and therefore both foul play injuries and non-foul play injuries. As all non-contact injuries were non-foul in terms of cause, they could potentially have distinguished non-foul play injuries from foul play injuries, due to some different underlying risk factors for contact and non-contact injuries. This was also a potential source of bias in the present thesis. All injuries were included in the analysis, because we wanted to investigate whether foul play injuries display some characteristics that distinguish them from all other injuries. Despite the potential bias, no significant differences in the injury incidence of foul play injuries and non-foul play injuries were observed depending on different match periods. This suggests that non-contact and contact injuries probably share similar underlying, and partly unknown, risk factors. Based on the results of the present thesis, one of these risk factors is a large total number of fouls in a match.

5.8 Video analysis – injuries were difficult to identify

Study IV aimed to identify variables (and variable categories) associated with a high risk of injury by combining previously described video analysis methodologies with data obtained from the prospective injury-surveillance system. Surprisingly, only 42% of the contact injuries reported by team physicians within the prospective injury-surveillance system could be linked to injury risk incidents, as defined in the FIA methodology, which involved player-to-player contact. The percentage of injuries that could be linked to incidents is so low that the descriptive data obtained from these definitions can hardly be considered to represent a general overview of playing actions and match circumstances leading to contact injuries. The results of the present thesis therefore strongly question whether the definition of an injury risk incident, as defined in the FIA methodology,[72] is appropriate for this type of epidemiological research on football injuries.

In the present thesis, a medical attention definition of injury was applied. In contrast, previous studies applying the FIA methodology, which have combined data obtained through video analysis with medical data, have defined injuries on a time-loss basis.[70, 72, 74] In previous FIA studies, it has been possible to link 43-54% of all reported injuries to injury risk incidents, for both contact and non-contact injuries, albeit with a tendency towards a higher percentage of identification for contact injuries.[70, 74] The broader definition of injury used in the present thesis may help to explain the lower percentage of injuries that can be linked to incidents compared with the previous studies applying the FIA definitions. Time-loss injuries are, by definition, more severe than injuries that do not result in time loss. The circumstances of time-loss injuries may therefore be more visible and thus easier to detect on video recordings. In other words, it is possibly easier to link time-loss injuries to match events on video recordings. The present thesis (Study IV) considered all contact injuries equally and did not differentiate between injuries of different types or different locations.

The percentage of injuries identified on video recordings was too low to draw any conclusions about the risk of injury associated with the various variables included in the analysis. This low percentage was achieved, despite including only injury risk incidents, resulting from player-to-player contact, in the analysis. One major concern related to this low percentage is that common yet unknown factors may characterise the injuries that are not identified. It may therefore be necessary to re-define what constitutes an injury risk incident. This is supported by a previous study by Tscholl et al.[131] on the cause of injuries in top-level female football. These authors combined medical data with data obtained through video analysis and found differences between the tackle mechanisms associated with injuries and those associated with injury risk incidents (as defined in the FIA methodology).[131] In accordance with the authors of Study IV, Tscholl et al.[131] also questioned the validity of the current FIA injury risk incident definition. A scientific investigation into the way injuries manifest themselves during matches on video material remains to be made. This could potentially provide useful information for a re-definition of what constitutes an injury risk incident.

According to the FIA methodology, the definition of an injury risk incident is any situation during a match, in which the match is interrupted by the referee, when a player is on the ground for more than 15 seconds, or the player appears to be in pain or receives medical treatment.[70, 72, 74, 159, 161] One problem is that there may be numerous other situations that fulfil the criteria of an injury risk incident, such as player substitutions, offsides or when a player is purely time-wasting, among others, which might not be related in any way to the risk of injury. In the present thesis, the exclusion of injury risk incidents that did not involve player-to-player contact probably reduced the number of these other situations included in the analysis. It is also questionable whether on-pitch medical treatment is a relevant criterion for an injury risk incident. It could be argued that on-pitch medical attention is only needed in cases when the player, coach, or a member of the medical staff evaluates the situation as having the potential to cause an injury. However, Fuller et al.[73] have previously found that post-match injury reports correlate poorly with post-match medical attention. In their data, most post-match physicians' reports were not associated with on-pitch medical attention (identified on video recordings). Whether or not some degree of under-reporting occurs in the post-match injury surveillance is unclear. The present thesis did not take account of the frequencies of the different injury risk incident criteria, when identifying injury risk incidents. This makes it impossible to draw conclusions about whether some of the criteria, such as on-pitch medical treatment, are more suitable for linking injury risk incidents with post-match injury reports. In the following paragraphs, contact injury risk incidents will be referred to as incidents.

5.9 Assessing injury risk associated with video analysis variables

The present thesis identified "attack type" and "involvement of foul play" as variables with an injury-predictive value. From the tackle analysis, the parameter "tackle action" was the only parameter for which the categories differed significantly. Although these results could indicate that some degree of injury risk is associated with these variables, it is impossible to draw any conclusions. The reason for this is that the total frequencies of the variables and categories during a match are not assessed, when applying the FIA methodology. The risk of injury associated with the variables (and categories) is therefore impossible to calculate. Consequently, based on the present data, we can only conclude that the presence of some categories of the variables "attack type", "foul play" and "tackle action" during an incident had an injury-predictive value. Whether or not the variable (or variable category) itself has an injury-predictive value remains unclear, as the total numbers were not recorded. In the present thesis, these limitations also apply in the same way to the tackle analysis. As the included tackles were chosen from the cohort of identified incidents, other tackles, some of which may have caused injuries, were most probably excluded.

If we hypothetically consider that the variables identified as independent predictors of injury do, in fact, indicate a real risk of injury, the finding that the involvement of a foul in an incident was associated with a lower percentage of linkable injuries, compared with incidents in which a foul was not involved, appears counter-intuitive. Several underlying methodological reasons may be speculated upon. A foul, as interpreted by the match referee, usually results in an interruption of the match, which is the first criterion for an injury risk incident, according to the FIA methodology. As a result, situations in which player-to-player contact occurred might have resulted in incidents relatively more often than non-contact situations. Similarly, other contact situations that did not involve a foul and a consequent interruption and that may have caused some of the excluded injuries were likely not to fulfil the criteria of an injury risk incident. It should be highlighted that only eight of the original nineteen FIA variables [72] were included in the analysis in the present thesis. So, a discussion of the relevance of the actual variables included in the FIA methodology is impossible based on the results of the present thesis.

It should also be remembered that the post-match injury-surveillance system could also represent a source of bias and consequently complicate the researchers' (conducting the video analysis) work in identifying the injury events. As described in the methods section of this thesis, the injury-surveillance data are based on post-match medical assessments of players. In post-match circumstances, the times (minutes) of injury may sometimes be approximations instead of the exact minutes. As the team physicians filled in the injury reports manually in post-match conditions, the minute of injury may have been difficult to assess, at least in some cases. The time of injury is often one of the crucial data items on the injury report form, when it comes to helping the researcher to identify the injury events on video material.

5.10 Video analysis (Study IV) - what can we learn?

As stated above, in the light of the present results, the FIA definitions require further development, as is probably also true of video analysis methodologies in general. In order to investigate the role of certain game-related variables in the injury risk, using video analysis methodologies, the optimal approach may be to focus on a few well-defined playing actions. The total frequencies of the variables of interest during matches should be assessed, in order to properly assess the injury risk associated with them. This approach has been used before, for example, in studies by Fuller et al.[71, 73, 129] of tackle parameters in international football. These studies recorded all the tackles identified on video recordings, in contrast to the present thesis which only included those resulting in injury risk incidents. Consequently, Fuller et al.[71] were able to identify some tackle parameters with a greater propensity to cause injuries than others. They concluded that initiating events with a high frequency of occurrence and a low propensity to cause injuries and events with a low frequency of occurrence and a high propensity to cause injuries should be differentiated, in order to assess the association of certain factors with injuries. When the frequencies of all variables (and categories) or factors are not recorded, this differentiation is impossible to make, as is the case in the present thesis. In line with this, Drawer et al.[200] stated that an effective risk management strategy begins with an estimation and evaluation of the risks associated with the activity.

The approach of recording the total frequencies of all variables may, on the other hand, present challenges of other kinds. This is demonstrated by comparing the results of the study by Fuller et al.[71] on tackle parameters with the results of a study relying on injury-surveillance data alone.[53] Both studies included the same injury report data from various tournaments.[53, 71] The comparison of the results from one of the tournaments (2000 Olympics) reveals that 96% (98/102) of all contact injuries reported within the injury-surveillance system could be linked to tackles identified on video material.[53, 71] This would intuitively indicate that the video analysis method was suitable. However, Fuller et al.[71] identified 8,572 tackles from 123 matches, which could roughly also be expressed as 70 tackles per match, or more than one tackle every two minutes. Considering these numbers, it appears possible that a player could be involved in several tackles during the same match and within a short time frame. Consequently, the reliable linking of a post-match injury report form to a tackle identified on video material may be questionable, as it is based on the researcher's assumption. This could be the case, especially regarding slight and minimal injuries, as they may be more difficult to detect on video recordings.

5.11 Limitations

5.11.1 General limitations – injury-surveillance data

With regard to the prospective injury-surveillance data, there are some potential sources of bias.

- Timing of injuries: considering that team physicians filled in the injury report manually in post-match conditions, it appears possible that some reported injury times may be approximations instead of exact minutes. A change in the score, or a PGDI that occurred in close proximity to an injury, may therefore have been a potential source of bias in some cases.
- With the exception of Study III, injury types, locations or the severity of injuries were not taken into account in the analyses.
- With the lack of injury follow-up, the accuracy of post-match diagnoses and of the estimations of injury severity is impossible to assess. Many players return to their clubs after international tournaments, shifting the responsibility for injury follow-up, treatment and rehabilitation to the clubs' medical staff.
- As no data on the applied playing formations were included in the match statistics, the hypothetical 1:4:4:2 formation (one goalkeeper, four defenders, four midfielders and two forwards) was applied to calculate the injury incidence for the different playing positions. However, it is probable that teams applied different formations.

In general, it was arguably a strength of the methodology to use a prospectively designed injury report for each injury, as has been used in several previous studies. Simultaneously, the report limits the description of the injury incident to the pre-determined factors. Moreover, some injuries might have initially manifested themselves during matches with only minor symptoms. An injury with minor initial minor symptoms may have worsened during a later stage of the match, with a more apparent onset. Some primary injuries may therefore have been overlooked in the present data.

5.11.2 Limitations of assessing the association between recovery time and injury incidence

The present thesis calculated the exposure times based on the number of players on the field and match length. Individual player exposures were therefore not recorded. This presents a possible source of bias in the assessment of the association between recovery time and injury incidence. It is possible that teams applied squad rotation, in other words, used different players during different matches depending on their recovery status. It is also possible that minor and slight injuries forced teams to rest players in matches that were played after a short recovery period. Players with minor injuries who returned to play after a longer recovery period may have run an increased risk of a re-injury, compared with players that had suffered no injuries. This could theoretically in part explain the higher injury incidence after a longer recovery time. In the present thesis, these factors were impossible to adjust for, as individual exposure and player substitutions were not taken into account.

5.11.3 Limitations of Study II

The definition of PGDIs was based on an hypothesis and excluded some other match interruptions, thereby presenting a potential source of bias. These other interruptions, such as goal kicks, player substitutions, free kicks, among others, may have allowed the players to take a short break and consequently had a calming effect on the following course of the match. Moreover, differences between the relative effects of the different factors included in the definition of a PGDI (yellow and red cards, injuries and goals) on injury incidence were not taken into account. The match events defined as PDGIs were chosen because of their hypothetically major effect on the subsequent course of the match. However, other factors, such as aggressive or insulting comments by players or fans, personal frustrations, possible refereeing errors and disallowed goals, among perhaps countless others, which could potentially affect the course of a match, may have similar effects. One methodological issue regarding these other (excluded) factors is that data on all of them may be impossible to obtain, making their significance therefore difficult to assess.

The choice of including the minute when a PGDI occurred in the following five-minute period in the analysis of the association between the timing of PGDIs and injury incidence may present a further source of bias. In cases in which the injury situation resulted in a yellow or red card being awarded by the match referee, this would arguably bias the data. A brief retrospective review of the data reveals that, for 16/412 (3.9%) of the foul play injuries included in the analysis, a red or yellow card was awarded during the same minute. This would therefore account for roughly 1.7% (16/939) of the total of yellow and red cards awarded in the tournaments and 0.9% (16/1833) of all PGDIs in the three tournaments. It appears unlikely that a proportion this small could have accounted entirely for the substantial, and statistically significant, difference in injury incidence between the narrow match periods following PGDIs and other match periods. Unfortunately, based on match statistics and injury report data, it is impossible to assess whether the PGDI, or the injury, occurred first.

All reported injuries were included in the definition of a PGDI. It might be argued that only acute injuries that result in a clear interruption of the game should be included, as some other injuries (or their symptoms) may occur with a gradual onset (i.e. some overuse injuries), not reach the consciousness of many players simultaneously and consequently have a moderate impact on the course of the match. However, there appear to be no reliable tools available for assessing which injuries the players, team management and referees become aware of at the specific moment of injury and, furthermore, whether some injuries affect the subsequent course of the match more than others.

Half-time breaks may have a transitory calming effect on the game. However, they were not taken into account in the analysis of injury incidence following PGDIs. PGDIs that occurred in the final minutes of the first half may thus have had a lesser impact during the initial minutes of the following second half, compared with PGDIs during other match periods.

5.11.4 How to define foul play (Study III)

In general, referees (as experts in the laws of the game) may be the individuals best suited to determining the involvement of a foul in a contact injury. In the present thesis, the involvement of a foul was assessed by the team physician and/or injured player. However, referees' decisions are affected by match circumstances and the time frame for decision-making is very narrow during matches. The team physician can base the post-match evaluation of the situation on several factors with more time, compared with the referee. The team physician can base his/her estimate on incident description by the injured player, clinical examination of the injured player, discussion with other team staff, referees' decision, his/her own vision of the incident and, in some cases, post-match video recordings. It might thus be easier for the team physician, in post-match conditions, to evaluate the involvement of a foul in specific contact situations.

5.11.5 Should non-contact injuries have been excluded from Study III?

All foul play injuries were caused by player-to-player contact, while all non-contact injuries did not involve a foul. This could be a possible source of bias: non-contact injuries might have distinguished non-foul play injuries from foul play injuries, due to differences between the risk factors for contact injuries and non-contact injuries. However, (despite the potential bias) we found that the incidences of foul play injuries and non-foul play injuries followed the same pattern with regard to variations between match periods and between drawing, losing and winning teams. This may suggest that non-contact injuries and contact injuries share similar underlying, and partly unknown, risk factors. In this case, it would thus appear to have been appropriate to include them in the same analysis.

5.11.6 Limitations of video analysis

Despite the arguably high quality of both the injury report data and the video recordings, the most important limitation of the video analysis methodology was the low percentage of injury identification (based on injury reports) on video recordings, which makes the interpretation of the results challenging, if not impossible. As discussed above, the reliable identification of injuries on video recordings appears to be a general limitation of video analysis methods in epidemiological football injury studies. This limitation may be a consequence of both the definitions applied in the video analysis methodologies and the injury-surveillance methodologies. Both these methodologies may contribute to the difficulties in identifying injuries on video recordings. Future studies, focusing on increasing the reliability of injury identification on video recordings, are therefore necessary.

CONCLUSIONS

Match events, such as goals (changes in the score), injuries, red and yellow cards, as well as fouls, are associated with injury incidence during men's World Cup football. The variation in injury incidence during different match periods in football is significant and this variation is partly related to these extrinsic factors. The injury incidence is also different for teams currently drawing, losing or winning a match, with players in teams that lead a match running a higher risk of injuries compared with players in drawing or losing teams. The injury incidence in World Cup football is also different for different playing positions, with forwards running the greatest risk of suffering injuries. Players, coaches, referees and team personnel may benefit from taking precautions during the match conditions in which the risk of injury is high. Combining video analysis methodologies with data obtained through other sources may complement our knowledge of the epidemiology of football injuries, but the currently available methodologies require further development when it comes to analysing playing actions and match circumstances leading to injuries.

FUTURE PERSPECTIVES

FOR RESEARCHERS, CLINICIANS, CLUBS AND FOOTBALL ASSOCIATIONS

The present thesis has focused on only one level of football. Whether the same phenomena apply in women's football, in different age groups, in full-season league football and at lower levels of football remains a question for future studies. Moreover, the underlying reasons for the phenomena observed in Studies I-III remain unknown and constitute another interesting and important subject for future research. This type of research is also crucial when it comes to determining the extent of the injury-prevention potential associated with the findings in the present thesis.

Considering the findings in the present thesis, coaches, players, referees and team medical personnel, participating in World Cup football, may profit from taking precautions during match periods identified in the present thesis as those in which the risk of injury is high, in order to prevent injuries during the match. However, the different possible precautions, as well as their efficacy in terms of injury prevention, remain to be assessed by future research. Temporary expulsions for unsportsmanlike behaviour during football matches have been discussed. Based on the findings in Study II, testing temporary expulsions in football, as well as their effect on injury incidence, would be an interesting topic for an epidemiological football injury study. Post-match sanctions, based on video material, on deliberate or violent offences could be another theoretical way to reduce injuries. Post-match sanctions are already in use, but they appear to be limited to the most reprehensible offences. Even though changes to the laws of the game may be difficult to implement, especially in popular sports with a long history, there are some encouraging examples when changes of this kind have been successful. Encouraging football associations, teams, players and teams' medical personnel to engage in injury prevention, as well as in research on the epidemiology of football injuries, are probably crucial components of success.

In general, both previous research and the findings in this thesis demonstrate that the role of team management (especially coaches) in injury prevention is crucial. It is encouraging that most clubs playing at top level are engaged to some extent in injury prevention. As stated in the introduction, improving internal communication within clubs is a challenge that will require efforts from different levels of team staff, in order to engage all levels in injury prevention. Improving the communication between the medical staff and team management may be especially important from an injury-prevention perspective. Considering the possible differences in the epidemiology of football injuries between genders, as well as different age groups, skill levels and playing positions, it appears possible that injury-prevention measures should be targeted according to the specific population of interest. These differences remain largely unknown and future research should assess them in order to identify the most efficient strategies for the group of interest.

The methodologies used in Studies I-III are new, when it comes to combining data from different sources, and the results suggest that future research may benefit from including match statistics data in studies of the epidemiology of football injuries. The quality and coverage of both match statistics and injury data have experienced substantial improvements during the past few decades. This positive development is likely to continue and could result in future studies with intriguing new research questions. Although video analysis can add to our knowledge of the epidemiology of injuries in football, Study IV showed the need for the further development of the existing methods. Despite the existence of a variety of available and previously described methodologies, they all appear to share similar limitations.

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REFERENCES

1. *Reilly T, Cabri J, Araújo D. (2005) Science and Football V: The proceedings of the fifth world congress on science and football. London and New York, Routledge.*
2. *Fédération Internationale de Football Association – The Game. http://www.fifa.com/classicfootball/history/the-game/origins.html (accessed July 2014).*
3. *Encyclopedia Britannica - football. www.britannica.com/EBchecked/topic/550852/football (accessed July 2014).*
4. *Fédération Internationale de Football Association – The Organisation. http://www.fifa.com/aboutfifa/organisation (accessed July 2014).*
5. *Fédération Internationale de Football Association -Confederations. http://www.fifa.com/aboutfifa/organisation/confederations/index.html (accessed July 2014).*
6. *Dietschy P. Making football global? FIFA, Europe, and the non-european football world, 1912-74. Journal of Global History 2013;8(2):279–298.*
7. *Darby P. (2002) Africa, football and FIFA: politics, colonialism and resistance. Oxon, Frank Cass Publishers.*
8. *Tiesler NC, Coelho JN. (2008) Globalised Football. Nations and migration, the city and the dream. London and New York, Taylor & Francis.*
9. *Fédération Internationale de Football Association – Laws of the Game 2014/2015. http://www.fifa.com/mm/document/football-development/refereeing/02/36/01/11/27%5f06%5f2014%5fnew--lawsofthegameweben%5fneutral.pdf (accessed September 2014).*
10. *Stolen T, Chamari K, Castagna C, Wisløff U. Physiology of soccer. Sports Med 2005;35(6):501–536.*
11. *Reilly T, Bangsbo J, Franks A. Anthropometric and physiological predispositions for elite soccer. Journal of Sports Sciences 2000;18(9):669–683.*
12. *Mohr M, Krustup P, Bangsbo J. Match performance of high-standard soccer players with special reference to development of fatigue. Journal of Sports Sciences 2003;21(7):519–528.*
13. *Di Salvo V, Baron R, Tschan H, Calderon Montero FJ, Bachl N, Pigozzi F. Performance characteristics according to playing position in elite soccer. Int J Sports Med 2007;28(3):222–227.*
14. *Bloomfield J, Polman RCJ, O'Donoghue PG. Physical demands of different positions in FA Premier League soccer. J Sports Sci Med 2007;6(1):63–70.*

15. *Rösch D, Hodgson R, Peterson L, Graf-Baumann T, Junge A, Chomiak J, Dvorak J. Assessment and evaluation of football performance. Am J Sports Med 2000;28(Suppl. 5):29S–39S.*

16. *Kannekens R, Elferink-Gemser MT, Visscher C. Positioning and deciding: key factors for talent development in soccer. Scan J med Sci Sports 2011;21(6):846–852.*

17. *Ali A. Measuring soccer skill performance: a review. Scand J Med Sci Sports 2011;21(2):170–183.*

18. *Ward P, Williams AM. Perceptual and cognitive skill developement in soccer : the multidimentional nature of expert performance. J Sport Exerc Psychol 2003;25:93–111.*

19. *Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. J Sports Sci 2012;30(7):625–631.*

20. *Bangsbo J, Marcello Iaia F, Krustrup P. Metabolic response and fatigue in soccer. Inj J Sports Physiol Perform 2007;2(2):111–127.*

21. *Bradley PS, Sheldon W, Wooster B, Olsen P, Boanas P, Krustup P. High-intensity running in English FA Premier League soccer matches. J Sports Sci 2009;27(2):159–168.*

22. *Di Salvo V, Gregson W, Atkinson G, Tordoff P, Drust B. Analysis of high intensity activity in Premier League soccer. Int J Sports Med 2009;30(3):205–212.*

23. *Di Mascio M, Bradley PS. Evaluation of the most intense high-intensity running periods in English FA Premier League soccer matches. J Strength Cond Res 2013;27(4):907–915.*

24. *Vigne G, Dellal A, Gaudino C, Chamari K, Rogowski I, Alloatti G, Wong PD, Owen A, Hautier C. Physical outcome in a successful Italian Serie A soccer team over three consecutive seasons. J Strength Cond Res 2013;27(5):1400–1406.*

25. *Dellal A, Chamari K, Wong DP, Ahmaidi S, Keller D, Barros R, Bisciotti GN, Carling C. Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. Eur J Sports Sci 2010;11:51–59.*

26. *Rienzi E, Drust B, Reilly T, Carter JE, Martin A. Investigation of anthropometric and work-rate profiles of elite South American international soccer players. J Sports Med Phys Fitness 2000;40(2):162–169.*

27. *Nédélec M, McCall A, Carling C, Legall F, Berthoin S, Dupont G. Recovery in soccer: part I – post-match fatigue and time course of recovery. Sports Med 2012;42(12):997–1015.*

28. *Nédélec M, McCall A, Carling C, Legall F, Berthoin S, Dupont G. Recovery in soccer : part II - recovery strategies. Sports Med 2013;43(1):9–22.*

29. *World Health Organization. (2003) Health and development through physical activity and sport. Geneva. WHO.*

30. *United Nations office for Drug Control and Crime Prevention. (2002) Using sport for drug abuse prevention. https://www.unodc.org/pdf/youthnet/handbook_sport_english.pdf (accessed october 2014).*

31. *Blair SN, Morris JN. Healthy hearts — and the universal benefits of being physically active: physical activity and health. Ann Epidemiol 2009;19(4):253–256.*

32. *United Nations Inter-agency Task Force. (2003) Sport for development and peace: towards achieving the millennium development goals. Geneva. United Nations.*

33. *Naci H, Ioannidis JPA. Comparative effectiveness of exercise and drug interventions on mortality outcomes : metaepidemiological study. BMJ 2013;347:f5577.*

34. *Knols R, Aaronson NK, Uebelhart D, Fransen J, Aufdemkampe G. Physical exercise in cancer patients during and after medical treatment: a systematic review of randomized and controlled clinical trials. J Clin Oncol 2005;23(16):3830–3842.*

35. *Fong DY, Ho JW, Hui BP, Lee AM, Macfarlane DJ, Leung SS, Cerin E, Chan WY, Leung IP, Lam SH, Taylor AJ, Cheng KK. Physical activity for cancer survivors: meta-analysis of randomised controlled trials. BMJ 2012;344:e70.*

36. *Fletcher GF, Balady G, Blair SN, Blumenthal J, Caspersen C, Chaitman B, Epstein S, Sivarajan Froelicher ES, Froelicher VF, Pina IL, Pollock ML. Statement on exercise: benefits and recommendations for physical activity programs for all americans. A statement for health professionals by the Committee on Exercise and Cardiac Rehabilitation of the Council on Clinical Cardiology, American Heart Association. Circulation 1996;94(4):857–862.*

37. *Sarna S, Sahi T, Koskenvuo M, Kaprio J. Increased life expecantcy of world class male athletes. Med Sci Sports Exerc 1993;25(2):237–244.*

38. *Seabra AC, Seabra AF, Brito J, Krustup P, Hansen PR, Mota J, Rebelo A, Rêgo C, Malina RM. Effects of a 5-month football program on perceived psychological status and body composition of overweight boys. Scand J Med Sci Sports 2014;24(Suppl. 1):10–16.*

39. *Andersen LJ, Randers MB, Hansen PR, Hornstrup T, Schmidt JF, Dvorak J, Søgaard P, Krustup P, Bangsbo J. Structural and functional cardiac adaptations to 6 months of football training in untrained hypertensive men. Scand J Med Sci Sports 2014;24(Suppl. 1):27–35.*

40. *Helge EW, Andersen TR, Schmidt JF, Jørgensen NR, Hornstrup T, Krustup P, Bangsbo J. Recreational football improves bone mineral density and bone turnover marker profile in elderly men. Scand J Med Sci Sports 2014;24(Suppl. 1):98–104.*

41. *Mohr M, Lindenskov A, Holm PM, Nielsen HP, Mortensen J, Welhe P, Krustup P. Football training improves cardiovascular health profile in sedentary, premenopausal hypertensive women. Scand J Med Sci Sports 2014;24(Suppl. 1):36–42.*

42. *Andersen TR, Schmidt JF, Thomassen M, Hornstrup T, Frandsen U, Randers MB, Hansen PR, Krustrup P, Bangsbo J. A preliminary study: Effects of football training on glucose control, body composition, and performance in men with type 2 diabetes. Scand J Med Sci Sports 2014;24(Suppl. 1):43–56.*

43. *de Sousa MV, Fukui R, Krustrup P, Pereira RMR, Silva PRS, Rodrigues AC, de Andrade JL, Hernandez AJ, da Silva MER. Positive effects of football on fitness, lipid profile, and insulin resistance in Brazilian patients with type 2 diabetes. Scand J Med Sci Sports 2014;24(Suppl. 1):57–65.*

44. *Uth J, Hornstrup T, Schmidt JF, Christensen JF, Frandsen C, Christensen KB, Helge EW, Brasso K, Rørth M, Midtgaard J, Krustrup P. Football training improves lean body mass in men with prostate cancer undergoing androgen deprivation therapy. Scand J Med Sci Sports 2014;24(Suppl. 1):105–112.*

45. *Bruun DM, Krustrup P, Hornstrup T, Uth J, Brasso K, Rørth M, Christensen JF, Midtgaard J. "All boys and men can play football": A qualitative investigation of recreational football in prostate cancer patients. Scand J Med Sci Sports 2014;24(Suppl. 1):113–121.*

46. *Andersen TR, Schmidt JF, Nielsen JJ, Randers MB, Sundstrup E, Jakobsen MD, Andersen LL, Suetta C, Aagaard P, Bangsbo J, Krustrup P. Effect of football or strength training on functional ability and physical performance in untrained old men. Scand J Med Sci Sports 2014;24(Suppl. 1):76–85.*

47. *Fuller CW, Junge A, Dorasami C, DeCelles J, Dvorak J. '11 for Health' a football-based health education programme for children: a two-cohort study in Mauritius and Zimbabwe. Br J Sports Med 2011;45(8):612–618.*

48. *Fuller CW, Junge A, DeCelles J, Donald J, Jankelowitz R, Dvorak J. 'Football for Health' — a football-based health-promotion programme for children in South Africa: a parallel cohort study. Br J Sports Med 2010;4(8)4:546–554.*

49. *Fédération Internationale de Football Association – Big Count. http://www.fifa.com/worldfootball/bigcount/index.html (Accessed February 2012).*

50. *Junge A, Dvorak J, Graf-Baumann T. Football injuries during the World Cup 2002. Am J Sports Med 2004;32(Suppl. 1):23S–27S.*

51. *Dvorak J, Junge A, Grimm K, Kirkendall D. Medical report from the 2006 FIFA World Cup Germany. Br J Sports Med 2007;41(9):578–581.*

52. *Dvorak J, Junge A, Derman W, Schwellnus M. Injuries and illnesses of football players during the 2010 FIFA World Cup. Br J Sports Med 2011;45(8):626–630.*

53. *Junge A, Dvorak J, Graf-Baumann T, Peterson L. Football injuries during FIFA tournaments and the Olympic Games, 1998-2001. Am J Sports Med 2004;32(Suppl. 1):80S–89S.*

54. *Junge A, Dvorak J. Injury surveillance in the World Football Tournaments 1998-2012. Br J Sports Med 2013;47(12):782–788.*

55. *Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: the UEFA injury study. Br J Sports Med. 2011;45(7):553–558.*

56. *Hawkins RD, Fuller CW. A prospective epidemiological study of injuries in four English professional football clubs. Br J Sports Med 1999;33(3):196–203.*

57. *Hawkins RD, Hulse MA, 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(1):43–47.*

58. *Ekstrand J. Keeping your top players on the pitch: the key to football medicine at a professional level. Br J Sports Med 2013;47(12):723–724.*

59. *Junge A, Lamprecht M, Stamm H, Hasler H, Bizzini M, Tschopp M, Reuter H, Psych D, Wyss H, Chilvers C, Dvorak J. Countrywide campaign to prevent soccer injuries in Swiss amateur players. Am J Sports Med 2011;39(1):57–63.*

60. *Dvorak J, Junge A. Football injuries and physical symptoms. A review of the literature. Am J Sports Med 2000;28(Suppl. 5):3S–9S.*

61. *Ekstrand J, Hägglund M, Kristenson K, Magnusson H, Waldén M. Fewer ligament injuries but no preventive effect on muscle injuries and severe injuries: an 11-year follow-up of the UEFA Champions League injury study. Br J Sports Med 2013;47(12):732–737.*

62. *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(12):738–742.*

63. *Drawer S, Fuller C. Propensity for osteoarthritis and lower limb joint pain in retired professional soccer players. Br J Sports Med 2001;35(6)402–408.*

64. *Roos H. Increased risk of knee and hip arthrosis among elite athletes. Lower level exercise and sports seem to be "harmless". (Article in Swedish) Läkartidningen 1998;95(42):4606–4610.*

65. *van Mechelen W. Sports injury surveillance systems. 'One Size Fits All'? Sports Med 1997;24(3):164–168.*

66. *Hawkins RD, Fuller CW. Risk assessment in professional football: an examination of accidents and incidents in the 1994 World Cup finals. Br J Sports Med 1996;30(2):165–170.*

67. *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(4):326–332.*

68. *Andersen TE, Arnason A, Engebretsen L, Bahr R. Mechanisms of head injuries in elite football. Br J Sports Med 2004;38(6):690–696.*

69. *Withnall C, Shewchenko N, Gittens R, Dvorak J. Biomechanical investigation of head impacts in football. Br J Sports Med 2005;39(Suppl. 1):i49–i57.*

70. *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):626–631.*

71. *Fuller CW, Smith GL, Junge A, Dvorak J. The influence of tackle parameters on the propensity for injury in international football. Am J Sports Med 2004;32(Suppl. 1):43S–53S.*

72. *Andersen TE, Larsen Ø, Tenga A, Engebretsen L, Bahr R. Football incident analysis: a new video based method to describe injuries in professional football. Br J Sports Med 2003;37(3):226–232.*

73. *Fuller CW, Smith GL, Junge A, Dvorak J. An assessment of player error as an injury causation factor in international football. Am J Sports Med 2004;32(Suppl. 1):28S–35S.*

74. *Arnason A, Tenga A, Engebretsen L, Bahr. A prospective video-based analysis of injury situations in elite male football: football incident analysis. Am J Sports Med 2004;32(6):1459–1465.*

75. *Hägglund M, Waldén M, Bahr R, Ekstrand J. Methods for epidemiological study of injuries to professional football players: developing the UEFA model. Br J Sports Med 2005;39(6):340–346.*

76. *van Beijsterveldt AM, van de Port IG, Krist MR, Schmikli SL, Stubbe JH, Frederiks JE, Backx FJ. Effectiveness of an injury prevention programme for adult male amateur soccer players: a cluster-randomised controlled trial. Br J Sports Med 2012;46(16):1114–1118.*

77. *Leppänen M, Aaltonen S, Parkkari J, Heinonen A, Kujala UM. Interventions to prevent sports related injuries: a systematic review and meta-analysis of randomised controlled trials. Sports Med 2014 ;44(4) :473–86.*

78. *Junge A, Dvorak J. Soccer injuries: a review on incidence and prevention. Sports Med 2004;34(13):929–938.*

79. *Alentorn-Geli E, Myer GD, Silvers HJ, Samitier G, Romero D, Lázaro-Haro C, Cugat R. 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):705–729.*

80. *Alentorn-Geli E, Mendiguchía J, Samuelsson K, Musahl V, Karlsson J, Cugat R, Myer GD. Prevention of anterior cruciate ligament injuries in sports. Part 1: systematic review of risk factors in male athletes. Knee Surg Sports Traumatol Arthrosc 2014;22(1):3–15.*

81. *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. Br J Sports Med 2006;40(3):193-201.*

82. *Waldén M, Hägglund M, Ekstrand J. UEFA Champions League study: a prospective study of injuries in professional football during the 2001–2002 season. Br J Sports Med 2005;39(8):542–546.*

83. *M Waldén, M Hägglund, J Ekstrand. Football injuries during European Championships 2004-2005. Knee Surg Sports Traumatol Arthrosc 2007;15(9):1155–1162.*

84. *Hägglund M, Waldén M, Ekstrand J. Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. Br J Sports Med 2006;40(9):767–772.*

85. *Noya Salces J, Gómez-Carmona PM, Garcia-Marco L, Moliner-Urdiales D, Sillero-Quintana M. Epidemiology of injuries in First Division Spanish football. J Sports Sci 2014;32(3):1263–1270.*

86. *Morgan BE, Oberlander MA. An examination of injuries in Major League Soccer. The inaugural season. Am J Sports Med 2001;29(4):426–430.*

87. *Eirale C, Farooq A, Smiley FA, Tol JL, Chalabi H. Epidemiology of football injuries in Asia : a prospective study in Qatar. J Sci Med Sport 2013;16(2):113–117.*

88. *Ekstrand J, Gillquist J, Liljedahl SO. Prevention of soccer injuries. Supervision by doctor and physiotherapist. Am J Sports Med 1983;11(3):116–120.*

89. *Junge A, Rösch D, Peterson L, Graf-Baumann T, Dvorak J. Prevention of soccer injuries: a prospective intervention study in youth amateur players. Am J Sports Med 2002;30(5):652–659.*

90. *Arnason A, Sigurdsson SB, Gudmunsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in Football. Am J Sports Med 2004;32(Suppl. 1):5S–16S.*

91. *Chomiak J, Junge A, Peterson L, Dvorak J. Severe injuries in football players. Influencing factors. Am J Sports Med 2000;28(Suppl. 5):58S–68S.*

92. *Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic risk factors for groin injuries among male soccer players: a prospective cohort study. Am J Sports Med 2010;38(10):2051–2057.*

93. *Woods C, Hawkins RD, 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(1):36–41.*

94. *Werner J, Hägglund M, Waldén M, Ekstrand J. UEFA injury study: a prospective study of hip and groin injuries in professional football over seven consecutive seasons. Br J Sports Med 2009;43(13):1036–1040.*

95. *Fousekis K, Tsepis E, Poulmedis P, Athanasopoulos S, Vagenas G. Intrisnic risk factors of non-contact quadriceps and hamstring strains in soccer: a prospective study of 100 professional players. Br J Sports Med 2011;45(9):709–714.*

96. *Brink MS, Visscher C, Arends S, Zwerver J, Post WJ, Lemmink KA. Monitoring stress and recovery: new insights for the prevention of injuries and illnesses in elite youth soccer players. Br J Sports Med 2010;44(11):809–815.*

97. *Dvorak J, Junge A, Chomiak J, Graf-Baumann T, Peterson L, Rösch D, Hodgson R. Risk factor analysis for injuries in football players. Possibilities for a prevention program. Am J Sports Med 2000;28(Suppl. 5):69S–74S.*

98. *Ekstrand J, Timpka T, Hägglund M. Risk of injury in elite football played on artificial turf versus natural grass: a prospective two-cohort study. Br J Sports Med 2006;40(12):975–980.*

99. *Ekstrand J, Hägglund M, Fuller CW. Comparison of injuries sustained on artificial turf and grass by male and female elite football players. Scand J Med Sci Sports 2011;21(6):824–832.*

100. *Williams S, Hume PA, Kara S. A review of football injuries on third and fourth generation artificial turfs compared with natural turf. Sports Med 2011;41(11):903–923.*

101. *Dragoo JL, Braun HJ. The effect of playing surface on injury rate : a review of the current literature. Sports Med 2010;40(10):981–990.*

102. *Orchard J. Is there a relationship between ground and climatic conditions and injuries in football? Sports Med 2002;32(7):419–432.*

103. *Orchard JW, Waldén M, Hägglund M, Orchard JJ, Chivers I, Seward H, Ekstrand J. Comparison of injury incidences between football teams playing in different climatic regions. Open Access J Sports Med 2013;4:251–260.*

104. *Azubuike SO, Okojie OH. An epidemiological study of football (soccer) injuries in Benin City, Nigeria. Br J Sports Med 2009;43(5):382–386.*

105. *Ekstrand J, Waldén M, Hägglund M. A congested football calendar and the wellbeing 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.*

106. *Bengtsson H, Ekstrand J, Hägglund M. Muscle injury rates in professional football increase with fixture congestion: an 11-year follow-up of the UEFA Champions League injury study. Br J Sports Med 2013;47(12):743–747.*

107. *Junge A, Dvorak J. Injuries in female football players in top-level international tournaments. Br J Sports Med 2007;41(Suppl. 1):i3–i7.*

108. *Faude O, Junge A, Kindermann W, Dvorak J. Risk factors for injuries in elite female soccer players. Br J Sports Med 2006;40(9):785–790.*

109. *Giza E, Mithöfer K, Farrell L, Zarins B, Gill T. Injuries in women´s professional soccer. Br J Sports Med 2005;39(4):212–216.*

110. *Waldén M, Hägglund M, Magnusson H, Ekstrand J. Anterior cruciate ligament injury in elite football : a prospective three-cohort study. Knee Surg Sports Traumatol Arthrosc 2011;19(1):11–19.*

111. *Hägglund M, Waldén M, Ekstrand J. UEFA injury study - an injury audit of European Championships 2006 to 2008. Br J Sports Med 2009;43(7):483–489.*

112. *Price RJ, Hawkins RD, Hulse MA, Hodson A. The Football Association medical research programme: an audit of injuries in academy youth football. Br J Sports Med 2004;38(4):466–471.*

113. *Junge A, Dvorak J, Chomiak J, Peterson L, Graf-Baumann T. Medical history and physical findings in football players of different ages and skill levels. Am J Sports Med 2000;28(Suppl. 5):16S–21S.*

114. *Peterson L, Junge A, Chomiak J, Graf-Baumann T, Dvorak J. Incidence of football injuries and complaints in different age groups and skill-level groups. Am J Sports Med 2000;28(Suppl. 5):51S–57S.*

115. *Olsen L, Scanlan A, MacKay M, Babul S, Reid D, Clark M, Raina P. Strategies for prevention of soccer related injuries: a systematic review. Br J Sports Med 2004;38(1):89–94.*

116. *Junge A, Dvorak J, Rösch D, Graf-Baumann T, Chomiak J, Peterson L. Psychological and sport-specific characteristics of football players. Am J Sports Med 2000;28(Suppl. 5):22S–28S.*

117. *FIFPro World Players Union - About FIFPro. http://www.fifpro.org/en/com-share-your-content-title-messages/about-fifpro/about-fifpro (accessed June 2014).*

118. *Castagna C, Abt G, D´Ottavio S. Physiological aspects of soccer refereeing performance and training. Sports Med 2007;37(7):625–646.*

119. *Krustrup P, Helsen W, Randers MB, Christensen JF, MacDonald C, Rebelo AN, Bangsbo J. Activity profile and physical demands of football referees and assistant referees in international games. J Sports Sci 2009;27(11):1167–1176.*

120. *Bizzini M, Junge A, Bahr R, Helsen W, Dvorak J. Injuries and musculoskeletal complaints in referees and assistant referees selected for the 2006 FIFA World Cup: retrospective and prospective survey. Br J Sports Med 2009;43(7):490–497.*

121. *Bizzini M, Junge A, Bahr R, Dvorak J. Injuries of football referees: a representative survey of Swiss referees officiating at all levels of play. Scand J Med Sci Sports 2011;21(1):42–47.*

122. *Bizzini M, Junge A, Bahr R, Dvorak J. Injuries and musculoskeletal complaints in referees - a complete survey in the top divisions of the Swiss football league. Clin J Sports Med 2009;19(2):95–100.*

123. *Carling C, Le Gall F, Dupont G. Are physical performance and injury risk in a professional soccer team in match-play affected over a prolonged period of fixture congestion? Int J Sports Med 2012;33(1):36–42.*

124. *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.*

125. *Dellal A, Lago-Peñas C, Rey E, Chamari K, Orhant E. The effects of a congested fixture period on physical performance, technical activity and injury rate during matches in a professional soccer team. Br J Sports Med 2013 [Epub ahead of print] doi:10.1136/bjsports-2012-091290.*

126. *Djaoui L, Wong del P, Pialoux V, Hautier C, Da Silva CD, Chamari K, Dellal A. Physical activity during a prolonged congested period in a top-class European football team. Asian J Sports Med 2014;5(1):47–53.*

127. *Fédération Internationale de Football Association - Statistics. http://www.fifa.com/worldfootball/statisticsandrecords/ (accessed July 2014).*

128. *Junge A, Langevoort G, Pipe A, Peytavin A, Wong F, Mountjoy M, Beltrami G, Terrell R, Holzgraefe M, Charles R, Dvorak J. Injuries in team sport tournaments during the 2004 Olympic Games. Am J Sports Med 2006;34(4):565–576.*

129. *Fuller CW, Junge A, Dvorak J. An assessment of football referees´ decisions in incidents leading to player injuries. Am J Sports Med 2004;32(Suppl. 1):17S–22S.*

130. *Tscholl P, O´Riordan D, Fuller CW, Dvorak J, Gutzwiller F, Junge A. Causation of injuries in female football players in top-level tournaments. Br J Sports Med 2007;41(Suppl. 1):i8–i14.*

131. *Tscholl P, O´Riordan D, Fuller CW, Dvorak J, Junge A. Tackle mechanisms and match characteristics in women´s elite football tournaments. Br J Sports Med 2007;41(Suppl. 1):i15–i19.*

132. *Giza E, Fuller C, Junge A, Dvorak J. Mechanisms of foot and ankle injuries in soccer. Am J Sports Med 2003;31(4):550–554.*

133. *Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). Am J Sports Med 2011;39(6):1226–1232.*

134. *Arnason A, Andersen TE, Holme I, Engebretsen L, Bahr R. Prevention of hamstring strains in elite soccer: an intervention study. Scand J Med Sci Sports 2008;18(1):40–48.*

135. *Askling C, Karlsson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. Scand J Med Sci Sports 2003;13(4):244–250.*

136. *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(11):2296–2303.*

137. *Waldén M, Hägglund M, Ekstrand J. Time-trends and circumstances surrounding ankle injuries in men´s professional football: an 11-year follow-up of the UEFA Champions League study. Br J Sports Med 2013;47(12):748–753.*

138. *Woods C, Hawkins R, Hulse M, Hodson A. The Football Association Medical Research Programme: an audit of injuries in professional football: an analysis of ankle sprains. Br J Sports Med 2003;37(3):233–238.*

139. *Lundblad M, Waldén M, Magnusson H, Karlsson J, Ekstrand J. The UEFA injury study: 11-year data concerning 346 MCL injuries and time to return to play. Br J Sports Med 2013;47(12):759–762.*

140. *Blennow K, Hardy J, Zetterberg H. The neuropathology and neurobiology of traumatic brain injury. Neuron 2012;76(5):886–899.*

141. *Harmon KG, Drezner JA, Gammons M, Guskiewicz KM, Halstead M, Herring SA, Kutcher JS, Pana A, Putukian M, Roberts WO. American Medical Society for Sports Medicine position statement: concussion in sport. Br J Sports Med 2013;47(1):15–26.*

142. *Fuller CW, 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–i9.*

143. *Nilsson M, Hägglund M, Ekstrand J, Waldén M. Head and neck injuries in professional soccer. Clin J Sports Med 2013;23(4):255–260.*

144. *Neselius S, Brisby H, Theodorsson A, Blennow K, Zetterberg H, Marcusson J. CSF-biomarkers in Olympic boxing: diagnosis and effects of repetitive head trauma. PLoS One 2012;7(4):e33606.*

145. *Vann Jones SA, Breakey RW, Evans PJ. Heading in football, long-term cognitive decline and dementia: evidence from screening retired professional footballers. Br J Sports Med 2014;48(2):159–161.*

146. *Toth C, McNeil S, Feasby T. Central nervous system injuries in sport and recreation: a systematic review. Sports Med 2005;35(8):685–715.*

147. *Fédération Internationale de Football Association - History: The Laws. http://www.fifa.com/classicfootball/history/the-laws/from-1863-to-present.html (accessed August 2014).*

148. *Fédération Internationale de Football Association – Law 12: Fouls and misconduct. http://www.fifa.com/mm/document/afdeveloping/refereeing/law_12_fouls_misconduct_en_47379.pdf (accessed March 2013).*

149. *Taylor L, Fitch N, Castle P, Watkins S, Aldous J, Sculthorpe N, Midgley A, Brewer J, Mauger A. Exposure to hot and cold environmental conditions does not affect the decision making ability of soccer referees following an intermittent sprint protocol. Front Physiol 2014;5:185.*

150. *Mallo J, Frutos PG, Juarez D, Navarro E. Effect of positioning on the accuracy of decision making of association football top-class referees and assistant referees during competitive matches. J Sports Sci 2012;30(13):1437–1445.*

151. *Downward P, Jones M. Effects of crowd size on referee decisions: analysis of the FA Cup. J Sports Sci 2007;25(14):1541–1545.*

152. *Biasca N, Wirth S, Tegner Y. The avoidability of head and neck injuries in ice hockey: an historical review. Br J Sports Med 2002;36(6):410–427.*

153. *Mcintosh AS, McCrory P. Preventing head and neck injury. Br J Sports Med 2005;39(6):314–318.*

154. *Carling C, Dupont G. Are declines in physical performance associated with a reduction in skill-related performance during professional soccer match-play? J Sports Sci. 2011;29(1):63–71.*

155. *Junge A. The influence of psychological factors on sports injuries. Review of the literature. Am J Sport Med 2000;28(Suppl. 5):10S–15S.*

156. *Fuller CW. An assessment of the relationship between behaviour and injury in the workplace: a case study in professional football. Safety Science 2005;43:213–224.*

157. *Rascle O, Traclet A, Souchon N, Coulomb-Cabagno G, Pertucci C. Aggressor-victim dissent in perceived legitimacy of aggression in soccer: the moderating role of situational background. Res Q Exerc Sport 2010;81(3):340–348.*

158. *Rahnama N, Reilly T, Lees A. Injury risk associated with playing actions during competitive soccer. Br J Sports Med 2002;36(5):354–359.*

159. *Andersen TE, Engebretsen L, Bahr R. Rule violations as a cause of injuries in male Norwegian professional football: are the referees doing their job? Am J Sports Med 2004;32(Suppl. 1):62S–68S.*

160. *Krosshaug T, Andersen TE, Olsen OE, Myklebust G, Bahr R. Research approaches to describe the mechanisms of injuries in sport: limitations and possibilities. Br J Sports Med 2005;39(6):330–339.*

161. *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(9):774–778.*

162. *Ekstrand J, Gillquist. The frequency of muscle tightness and injuries in soccer players. Am J Sports Med 1982;10(2):75–78.*

163. *Ekstrand J, Gillquist J. The avoidability of soccer injuries. Int J Sports Med 1983;4(2):124–128.*

164. *Ekstrand J, Gillquist J, Möller M, et al. Incidence of soccer injuries and their relation to training and team success. Am J Sports Med 1983;11(2):63–67.*

165. *Kirkendall DT, Junge A, Dvorak J. Prevention of football injuries. Asian J Sports Med 2010;1(2):81-92.*

166. *McCall A, Carling C, Nedelec M, Davison M, Le Gall F, Berthoin S, Dupont G. Risk factors, testing and preventive strategies for non-contact injuries in professional football: current perceptions and practices of 44 teams from various premier leagues. Br J Sports Med 2014;48(18):1352-1357.*

167. *Steffen K, Myklebust G, Olsen OE, Holme I, Bahr R. Preventing injuries in female youth football — a cluster-randomized controlled trial. Scand J Med Sci Sports 2008;18(5):605–614.*

168. *Soligard T, Myklebust G, Steffen K, Holme I, Silvers H, Bizzini M, Junge A, Dvorak J, Bahr R, Andersen TE. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. BMJ 2008;337:a2469.*

169. *Soligard T, Nilstad A, Steffen K, Myklebust G, Holme I, Dvorak J, Bahr R, Andersen TE. Compliance with a comprehensive warm-up programme to prevent injuries in youth football. Br J Sports Med 2010;44(11):787–793.*

170. *Bizzini M, Junge A, Dvorak J. Implementation of the FIFA 11+ football warm up program: how to approach and convince the football associations to invest in prevention. Br J Sports Med 2013;47(12):803–806.*

171. *Heidt RS Jr, Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. Am J Sports Med 2000;28(5):659–662.*

172. *Emery CA, Meeuwisse WH. The effectiveness of a neuromuscular prevention strategy to reduce injuries in youth soccer: a cluster-randomised controlled trial. Br J Sports Med 2010;44(8):555–562.*

173. *Swart E, Redler L, Fabricant PD, Mandelbaum BR, Ahmad CS, Wang YC. Prevention and screening programs for anterior cruciate ligament injuries in young athletes : a cost-effectiveness analysis. J Bone Joint Surg Am 2014;96(9):705–711.*

174. *Alentorn-Geli E, Myer GD, Silvers HJ, Samitier G, Romero D, Lázaro-Haro C, Cugat R. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 2: a review of prevention programmes aimed to modify risk factors and to reduce injury rates. Knee Surg Sports Traumatol Arthrosc 2009;17(8):859–879.*

175. *Grindstaff TL, Hammill RR, Tuzson AE, Hertel J. Neuromuscular control training programs and noncontact anterior cruciate ligament injury rates in female athletes: a numbers-needed-to-treat analysis. J Athl Train 2006;41(4):450–456.*

176. *Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. Knee Surg Sports Traumatol Arthrosc 1996;4(1):19–21.*

177. *Alentorn-Geli E, Mendiguchía J, Samuelsson K, Musahl V, Karlsson J, Cugat R, Myer GD. Prevention of non-contact anterior cruciate ligament injuries in sports. Part II: systematic review of the effectiveness of prevention programmes in male athletes. Knee Surg Sports Traumatol Arthrosc 2014;22(1):16–25.*

178. *Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. Am J Sports Med 1985;13(4):259–262.*

179. *Mohammadi F. Comparison of 3 preventive methods to reduce the recurrence of ankle inversion sprains in male soccer players. Am J Sports Med 2007;35(6):922–926.*

180. *McGuine TA, Keene JS. The effect of a balance training program on the risk of ankle sprains in high school athletes. Am J Sports Med 2006;34(7):1103–1111.*

181. *Söderman K, Werner S, Pietilä T, Engström B, Alfredson H. Balance board training: prevention of traumatic injuries of the lower extremities in female soccer players? A prospective randomized intervention study. Knee Surg Sports Traumatol Arthrosc 2000;8(6):356–363.*

182. *Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Prevention of injuries among male soccer players: a prospective, randomized intervention study targeting players with previous injuries or reduced function. Am J Sports Med 2008;36(6):1052–1060.*

183. *Hägglund M, Atroshi I, Wagner P, Waldén M. Superior compliance with a neuromuscular training programme is associated with fewer ACL injuries and fewer acute knee injuries in female adolescent football players: secondary analysis of an RCT. Br J Sports Med 2013;47(15):974–979.*

184. *Delaney JS, Al-Kashmiri A, Drummond R, Correa JA. The effect of protective headgear on head injuries and concussions in adolescent football (soccer) players. Br J Sports Med 2008;42(2):110–115.*

185. *van Bejsterveldt AM, van der Horst N, van de Port IG, Backx FJ. How effective are excersise-based injury prevention programmes for soccer players? : A systematic review. Sports Med 2013;43(4):257–265.*

186. *Hägglund M, Waldén M, Ekstrand J. Lower reinjury rate with a coach-controlled rehabilitation program in amateur male soccer: a randomized controlled trial. Am J Sports Med 2007;35(9):1433–1442.*

187. *Rahnama N. Prevention of football injuries. Int J Prev Med 2011;2(1):38-40.*

188. *Lindblom H, Waldén M, Carlfjord S, Hägglund M. Implementation of a neuromuscular training programme in female adolescent football: 3-year follow-up study after a randomised controlled trial. Br J Sports Med 2014;48(19):1425–1430.*

189. *Fédération Internationale de Football Association – http://www.fifa.com/worldfootball/statisticsandrecords/tournaments/worldcup/organisation/index.html (accessed November 2011).*

190. *Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33(1):159–174.*

191. *Ekstrand J, Waldén M, Hägglund M. Risk for injury when playing in a national football team. Scand J Med Sci Sports 2004 Feb;14(1):34–38.*

192. *Aoki H, O´Hata N, Kohno T, Morikawa T, Seki J. A 15-Year prospective epidemiological account of acute traumatic injuries during official professional soccer league matches in Japan. Am J Sports Med 2012;40(5):1006–1014.*

193. *Lago-Peñas C, Dellal A. Ball possession strategies in elite soccer according to the evolution of the match-score: the influence of situational variables. J Hum Kinet 2010;25:93–100.*

194. *Gee CJ, Leith LM. Aggressive behaviour in professional ice-hockey: A cross-cultural comparison of North American and European born NHL players. Psychol Sport Exerc 2007;8(4):567–583.*

195. *Silva III JM. Behavioral and situational factors affecting concentration and skill performance. J Sport Exerc Psychol 1979;1(3):221–227.*

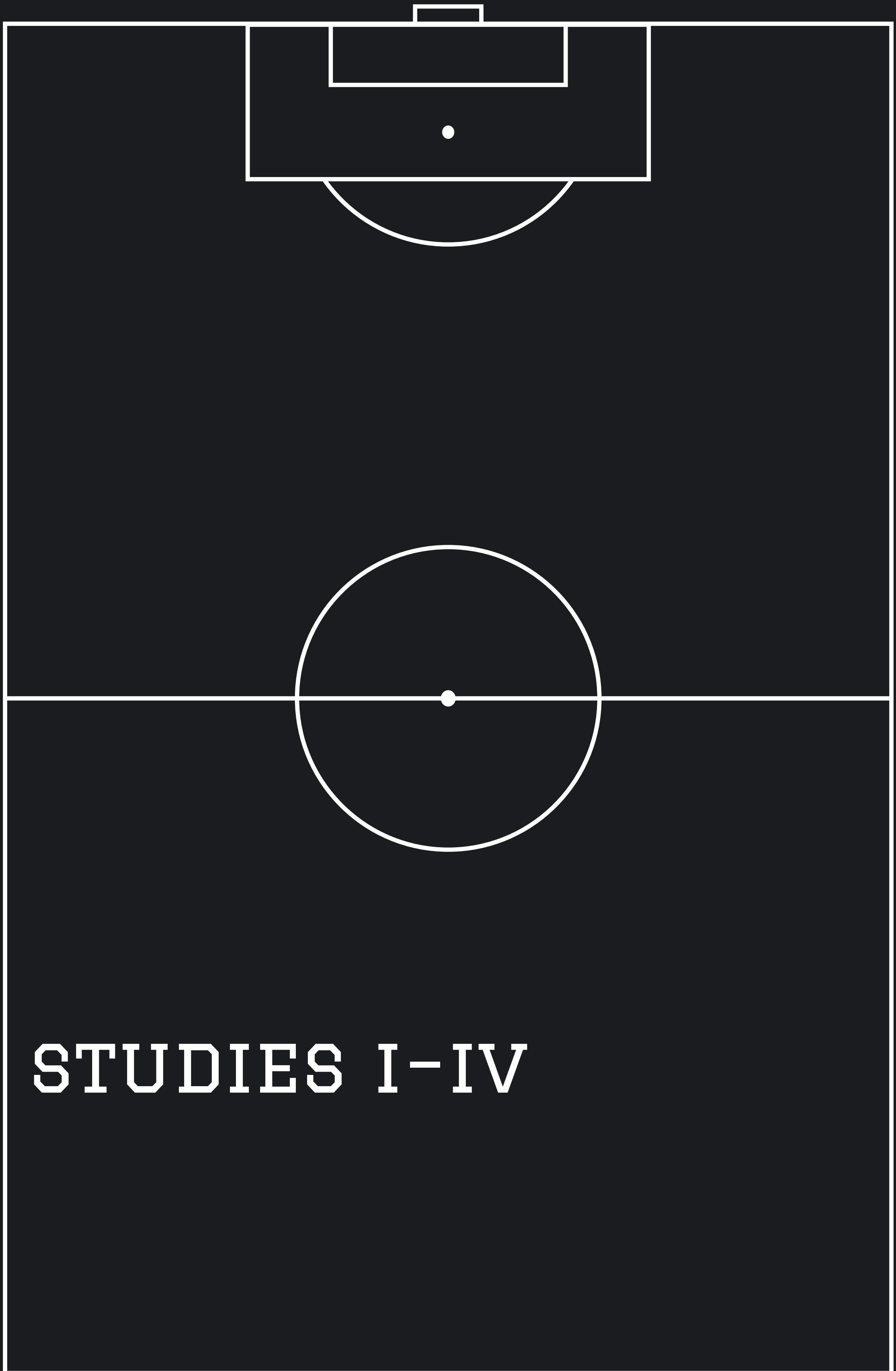
196. *Stanger N, Kavussanu M, Willoughby A, Ring C. Psychophysiological responses to sport-specific affective pictures: A study of morality and emotion in athletes. Psychol Sport Excerc 2012;13(6):840–848.*

197. *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(4):271–276.*

198. *Dupont G, Nedelec M, McCall A, McCormack D, Berthoin S, Wisløff U. Effect of 2 soccer matches in a week on physical performance and injury rate. Am J Sports Med 2010;38(9):1752–1758.*

199. *Gümüşdağ? H, Yıldıran İ, Yamaner F, Kartal A. Aggression and fouls in professional football. Biomed Hum Kinet 2011;3:67–71.*

200. *Drawer S, Fuller CW. Evaluating the level of injury in English professional football using a risk based assessment process. Br J Sports Med 2002;36(6):446–451.*



STUDIES I–IV

STUDY I

The effect of changes in the score on injury incidence during three FIFA World Cups

Jaakko Ryynänen, Astrid Junge, Jiri Dvorak, Lars Peterson, Jón Karlsson, Mats Börjesson

Br J Sports Med 2013; 47(15): 960–964.

STUDY II

Increased risk of injury following red and yellow cards, injuries and goals in FIFA World Cups

Jaakko Ryynänen, Jiri Dvorak, Lars Peterson, Hannu Kautiainen, Jón Karlsson, Astrid Junge, Mats Börjesson

Br J Sports Med 2013; 47(15): 970–973.

STUDY III

Foul play is associated with injury incidence: an epidemiological study of three FIFA World Cups (2002-2010)

Jaakko Ryynänen, Astrid Junge, Jiri Dvorak, Lars Peterson, Hannu Kautiainen, Jón Karlsson, Mats Börjesson

Br J Sports Med 2013; 47(15): 986–991.

STUDY IV

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

Jaakko Ryynänen,
Louis Leventer, Lars Peterson,
Hannu Kautiainen, Jón Karlsson,
Mats Börjesson, Colin W Fuller

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