Aus dem Bereich Sport- und Präventivmedizin
Klinische Medizin
der Medizinischen Fakultät
der Universität des Saarlandes, Homburg/Saar

Head Injuries in Professional Football (Soccer)

Dissertation zur Erlangung des Grades eines Doktors der Theoretischen Medizin
der Medizinischen Fakultät
der UNIVERSITÄT DES SAARLANDES

2019

vorgelegt von: Florian Beaudouin

geb. am: 07.09.1987 in Trier

DECLARATION

I Florian Beaudouin certify to the best of my knowledge and belief that this thesis does not:

i. Incorporate any material previously submitted for a degree or diploma in any institution of higher education without acknowledgement;

ii. Contain any material previously published or written by another person; where due reference is made in the text; or

iii. Contain any defamatory material

I also grant permission for the library at Saarland University to produce duplicate copies of my thesis as required.

Saarbrücken, 22.11.2018 ____________________

Florian Beaudouin

Table of Contents

For my family

In loving memory

of my father Yves

Acknowledgement

First and foremost a special thanks to my dear family who supported me not only throughout this PhD, but also throughout my whole life and my studies in Saarbrücken. This thesis would not have been possible without you. Thank you for your endless encouragement, support, and love. Very sadly and tragically, we had to experience the worst loss imaginable during my PhD, the loss of our father. Wherever you are, this thesis is for you. I hope you will keep watching my life with your hand on my shoulder as you have always done throughout my life. I miss you.

Of course I want to thank my supervisor Univ.-Prof. Dr. Tim Meyer for giving me the freedom to focus on my PhD and for entrusting me with various projects over the years as well as to focus on my occupational career outside the institute.

I also want to say thank you to my supervisor Dr. Karen aus der Fünten for your valuable and much appreciated guidance throughout my PhD as well as throughout the years we have been working together starting in 2014.

I greatly appreciate the help of Tobias Tröss with my analyses for my various publications.

A special thanks to my dear colleagues Dr. Sabrina Skorski and Dr. Sascha Schwindling for the pleasant and extremely cooperative collaboration over the years. I appreciate your help, support, and guidance throughout my PhD with your scientific and personal experience.

Thanks to Dr. Robert McCunn, Chris Thompson, and Univ.-Prof. Dr. Dr. Claus Reinsberger for your helpful comments on my various publications and this thesis.

Abbreviations

AMSSM	American Medical Society for Sports Medicine
ANAM	Automated Neuropsychological Assessment Metric
ARU	Australian Rugby Union
b	Regression Coefficient
BESS	Balance Error Scoring System
BISp	Bundesinstitut für Sportwissenschaft
CI	Confidence Interval
CISG	Concussion In Sport Group
CNS-VS	CNS-Vital Signs
CogState	Axon/CogState/CogSport
CT	Computed Tomography
CTE	Chronic Traumatic Encephalopathy
CTSIB	Clinical Test of Sensory Organization and Balance
DAI	Diffuse Axonal Injury
DFB	German Football Association
DFL	Die Liga – Fußballverband (Deutsche Fußball Liga)
DTI	Diffusion Tensor Imaging
qEEG	Quantitative Electroencephalography
FA	Football Association England
FIFA	Fédération Internationale de Football Association
fMRI	Functional Magnetic Resonance Imaging
h	Hour
ICH	Intracranial Hemorrhage
IFAB	International Football Association Board
ImPACT	Immediate Post-concussion and Cognitive Testing
IR	Incidence Rate
IRR	Incidence Rate Ratio
MCI	Mild Cognitive Impairment
MEG	Magnetoencephalography
MRI	Magnetic Resonance Imaging
MRS	Magnetic Resonance Spectroscopy

mTBI	Mild Traumatic Brain Injury
NFL	National Football League
NP	Neuropsychological Testing
p	p-value
PCS	Post-concussion Syndrome
PCSS	Post-Concussion Symptom Scale
PhD	Doctor of Philosophy
R^2	Coefficient of Determination
SAC	Standardized Assessment of Concussion
SCAT-5	Sport Concussion Assessment Tool 5
SIS	Second Impact Syndrome
SOT	Sensory Organization Test
SPECT	Single Photon Emission Computed Tomography
TBI	Traumatic Brain Injury
UEFA	Union of European Football Association
VOMS	Vestibular-Ocular-Motor Screening Test
χ^2	Chi-Square Test

Figures

List of Publications

1. **Beaudouin F**, aus der Fünten K, Tröss T, Reinsberger C & Meyer T. Time trends of head injuries over multiple seasons in professional male football (soccer). Sports Medicine International Open 2018; Accepted on Nov 13.
2. **Beaudouin F**, aus der Fünten K, Tröss T, Reinsberger C & Meyer T. Match situations leading to head injuries in professional male football (soccer) – a video-based analysis over 12 years. Clinical Journal of Sports Medicine 2018; Jan 19. doi: 10.1097/JSM.0000000000000572. [Epub ahead of print]
3. **Beaudouin F**, aus der Fünten K, Tröss T, Reinsberger C & Meyer T. Head injuries in professional male football (soccer) over 13 years – 29% lower incidence rates after of a rule change (red card). British Journal of Sports Medicine 2017; June 23. doi: 10.1136/bjsports-2016-097217. [Epub ahead of print]

Abstract

Introduction:

Head injuries in sports may have been an underestimated health risk for many years. However, they potentially bear the risk of serious long-term sequelae with a potential impact on the athletes' activities of daily living, sports, or career. Although the incidence of head injuries in professional football (soccer) is relatively low in comparison to so-called high-risk sports such as American football, rugby, boxing, or ice hockey, absolute numbers are substantial because of the high popularity of this sport and the large number of players. In 2006, a first step towards head injury prevention in football was made by altering a rule: henceforth intentional elbow to head contacts had to be punished by a red card. This action determined one of the three aims of this thesis: i) to present incidence rates of head injuries including their time trends and injury mechanisms; ii) to identify circumstances of head injury incidents, the behavior of referees, and their decisions; and iii) to investigate the effect of the rule change on the reduction of head injuries in professional male football.

Methods:

i) To investigate the time trends of head injuries, an analysis of head injuries in the 1st German Bundesliga was generated comprising the 11 consecutive seasons (2006/07 to 2016/17) following the rule change. The head injury database was based on continuously published data from the German football magazine "kicker Sportmagazin®" and other media sources. Injury mechanisms were analysed from video recordings. Injury incidence rates (IR) and 95% confidence intervals (95% CI) were calculated. Time trends were analysed via linear regression. ii) To identify circumstances of head injury incidents, the video analyses of all head injuries from 13 consecutive seasons (2000/01 to 2012/13) were screened. iii) To provide a description of injury mechanisms of head injuries and the effect of the rule change, the database of all head injuries comprising seasons 2000/01 to 2012/13 were screened and the equal number of seasons before and after the rule change were compared. Head injury mechanisms were analysed from video recordings. IRs and 95% CI as well as incidence rate ratios (IRR) to assess differences in injury rates six seasons before and six seasons after the rule change were calculated.

Results:

i) During the 11 consecutive seasons, 238 head injuries occurred during matches (IR 1.77 per 1000 match hours). There were no significant seasonal changes (expressed as annual average year-to-year change) in IRs over the 11-year period for total head injuries, facial and head fractures, head and face lacerations and abrasions, and head contusions. The average year-to-year increase for concussion was 6.4%. There were no seasonal changes in head injury mechanisms over the study period. ii) Most head injury incidents involved two players. Those players who suffered a subsequent head injury predominantly jumped (60%), headed the ball (36%), and ran forwards (20%), whereas the non-injured players mainly jumped (64%), headed the ball (27%), and raised the elbow to the head (23%). Free ball situations (two players challenging/dueling for the ball) caused the largest proportion of the head injuries (81%). iii) 356 head injuries were recorded (IR 2.22 per 1000 match hours) in 13 consecutive seasons. Contact with another player resulted in the greatest proportion of head injuries, especially head to head (34%) and elbow to head (17%) contacts. After the rule change the total number of head injuries was reduced by 29%. The subcategories head and face lacerations and abrasions declined by 42%, concussions by 29%, head contusions by 18% and facial and head fractures by 16%.

Discussion/Conclusion:

The first study in this thesis revealed that the subcategory concussion increased slightly over the (2006/07 to 2016/17) seasons, which could be the result of increasing match dynamics and/or a raised awareness for this injury type among team physicians and players. Total head injuries and the other subcategories remained reasonably stable over 11 consecutive seasons. The second study showed that heading duels are particularly associated with head injuries and could be target of future prevention strategies. The third study provided evidence that the incidence rates for total number of head injuries and their respective subcategories were lower in the six seasons after the rule change compared to the equal number of seasons before. Therefore, rule changes in football appear to be effective in reducing the occurrence of head injuries. To summarize, the increasing number of concussions requires action. Ongoing monitoring and surveying of head injuries allows practitioners to keep track of head injuries. For future research, the development of preventative measures to avoid potential (serious) health consequences of head injuries is warranted.

1 Introduction

In recent years, head traumas in sports have received increased attention. In particular concussions were subject of public discussions, predominantly in the United States of America. One of the most vividly debated issues has been the relationship between repetitive concussions and their long-term consequences (Harmon et al. 2013). Over the years, the need for validated measures to count and prevent such injuries has therefore increased in organizations within the scientific and the applied field of sports science and medicine. Since 2001, a multi-sports consensus conference on concussion in sport has regularly been organized in order to advance the knowledge of this particular head injury. These experts' meetings aim at improving the knowledge on pathophysiological aspects, diagnostic, and preventative measures. In 2017, the 5th consensus statement was published with updated recommendations and information on the definition of sports-related concussion, its signs and symptoms, imaging, management, recovery, and prevention (McCrory et al. 2017).

Initially, head injury research predominantly focused on high risk sports such as American football, rugby, or ice hockey. Despite the use of protective equipment (e.g. padding, helmets, scrum caps), these sports allow full body tackles/checks to the opponent, often at high velocities (Beckwith et al. 2013a, 2013b; Guskiewicz et al. 2011; Kuo et al. 2018). In American football incidence rates of 17.3 – 45.5 concussions per 1000 match hours were reported (Casson et al. 2010; Zuckermann et al. 2015). Ice hockey follows second with incidence rates of 4.4 – 26.5 concussions per 1000 match hours (Donaldson et al. 2013; Zuckermann et al. 2015) before rugby with incidence rates of 4.0 – 8.9 per 1000 match hours (Cross et al. 2016; Gissane et al. 2003).

The incidence of concussion rates in football (soccer) has also received more attention in recent years despite the lower collision and contact rates in comparison to the aforementioned sports (Harmon et al. 2013; Levy et al. 2012). As heading the ball is a sports-specific element of football (players intentionally deflect, stop, or redirect the ball) (Spiotta et al. 2012) and as total injury rates in football are high (Ekstrand et al. 2011), football players may also be at an increased risk for head injuries, for instance due to potential collisions with other players (Andersen et al. 2004; Fuller et al. 2005; Levy et al. 2012). Furthermore, football represents the most popular sports from professional to amateur levels worldwide. As a result, higher total numbers of head injuries seem plausible.

Determining head injury incidence rates and the corresponding mechanisms are the first steps with regards to injury prevention. High numbers would support the need for preventative measures. At present, specific data on head injuries in German football are limited. Compared to the other aforementioned contact sports the incidence rates of head injuries (particularly concussions) in elite football in Europe appear to be low. The first UEFA Champions League study by Waldén et al. (2005) reported an overall (training + match) incidence rate of head injuries of 0.32 per 1000 football hours. Additional research has reported various findings. A 7-year analysis by Ekstrand et al. (2011) identified an overall head injury incidence rate of 0.14 per 1000 football hours, which is low in comparison to 0.74 (Nilsson et al. 2013), 0.88 (Bjørnboe et al. 2013), and 1.70 (Andersen et al. 2004) head injuries per 1000 match hours. A very likely explanation of these varying incidence rates of head injuries is that some studies (Ekstrand et al. 2011; Waldén et al. 2005) included not only match, but also training exposure into their analyses. Injury rates in training are reported considerably lower compared to match and overall (comprising match and training injuries) rates (Ekstrand et al. 2013). Nilsson et al. (2013) reported a 38-fold higher rate of head injuries during matches compared with training and a 78-fold higher rate of concussions in matches. This emphasizes that head injuries in training seem negligible and can therefore be omitted as done in the present analyses.

The low number of concussions in football is to some extent likely a result of an underreporting and/or underdiagnosing. Concussions can easily be overlooked by non-medical professionals, inexperienced medical staff, and even highly qualified medical staff due to mild symptoms or even trivialized post-injury symptoms by the players themselves (Broglio et al. 2010; Feddermann-Demont et al. 2014; Khurana & Kaye 2012; Levy et al. 2012; Meehan et al. 2013; Meier et al. 2015; Putukian et al. 2009; Williamson et al. 2006). The estimated number of unreported concussions in professional football is still unknown, but it is estimated that as many as 30% remain undiagnosed throughout different sports (Meehan et al. 2013; Meier et al. 2015; Williamson et al. 2006). A study by Fuller (2005) reported a substantially higher incidence rate of head injuries of 12.5 per 1000 match hours with regard to international tournaments, which was matched by two other reports (Junge & Dvorák 2013; Junge & Dvorák 2015). The importance and the intensity of tournaments' games are usually very high. Losing a game might result in elimination from the tournament, which could suggest a more aggressive playing style resulting in an increase of all injuries including head injuries.

Head injury incidence rates vary tremendously through different studies. This circumstance is mainly due to different data collection approaches. The present data are media-based and publicly available, whereas other studies rely on data that are exclusively forwarded by medical staff of the teams to research teams. The present data (**study 3**) were collected by a structured search in the German football magazine ‘kicker Sportmagazin®’ established in 1968 (online since 1997). It is published biweekly online and as print media. One journalist is responsible for one club, having daily contact with their designated club (press office). The magazine contains a specific injury column. Additionally, injuries can be found using the free-text search tool. For **study 1**, along with data of the ‘kicker Sportmagazin®’, web pages (transfermarkt.de, ligainsider.de), social media channels of the players and teams (Twitter, Facebook, and Instagram), team homepages and newsletters, TV sports channels (e.g. Sky Sports News), and local news (e.g. newspapers) were also searched. The head injury mechanisms and match situations (**study 1, 2, and 3**) were captured on video recordings, which were obtained from the official German Football League (Die Liga – Fußballverband (DFL)) and from wyscout®.

The initial studies focusing on head injury mechanisms in football were conducted more than a decade ago. They identified the intentional use of the upper extremity towards the head, especially the use of the elbow, as one major factor for the occurrence of head injuries (Andersen et al. 2004; Fuller et al. 2005). Accordingly, the International Football Association Board (IFAB) adapted the rule of the game in 2006: Direct and deliberate “elbow to head” blows became punishable by an immediate red card. A systematic re-evaluation of the injury incidence rates and injury mechanisms before and after the aforementioned adaption of the rules has yet to be conducted. Furthermore, specific data on head injuries in German professional male football are scarce. This is of major interest as the German Football Association (DFB) represents the largest sports federation in the world.

To summarize, research regarding head injuries in professional football has increased in recent years, but is still limited worldwide. In order to estimate the risk of sustaining a head injury in football, an evaluation of the current incidence rates and the underlying injury mechanisms is crucial. Collecting these data is also the first step in the classical chain of injury prevention (van Mechelen et al. 1992). In 2006, a first action with regards to injury prevention was taken by introducing the aforementioned rule change regarding “elbow to head” blows. However, the efficacy of this preventative measure is still unknown.

Thus, the aims of this PhD project were: i) to investigate the time trends of head injuries in professional German football and their injury mechanisms; ii) to identify circumstances of head injury incidents; and (iii) to investigate the effect of the rule change in 2006 on the number and characteristics of head injuries. The present work is based on a media-based analysis of head injuries in the 1st German football league comprising 17 years overall (seasons 2000/01 – 2016/17, different time periods in **study 1, 2, and 3**). Although, the database focused on professional football, head injury types and their respective injury mechanisms may be transferred to lower leagues and less professional football as the same rules apply. **Study 2 and 3** of this PhD-thesis are part of the project “Expertise on Head Trauma in German Professional Sports” that was conducted from 2015 to 2016 and funded by the German Federal Institute of Sports Science (BISp – Bundesinstitut für Sportwissenschaft).

2 Background

2.1 Anatomy of the Head and Brain

Depending on the location of the impact on the head and the force of the impact, head injury type and its complications can vary tremendously.

The neurocranium (the occipital bone, the sphenoidal bone, the temporal bone, the parietal bone, and the frontal bone) and the splanchnocranium (nasal bone, maxilla, mandible, the ethmoidal bone, the lacrimal bone, and the zygomatic bone) (figure 1) can be affected by head injuries. The size of the aforementioned bones and the direction of impact to the head determine the likelihood of which bones/anatomical locations are affected by head injuries. As facial and head muscles are not involved in football-specific movements and are rarely affected in the light of head injuries, a detailed description was deliberately omitted.

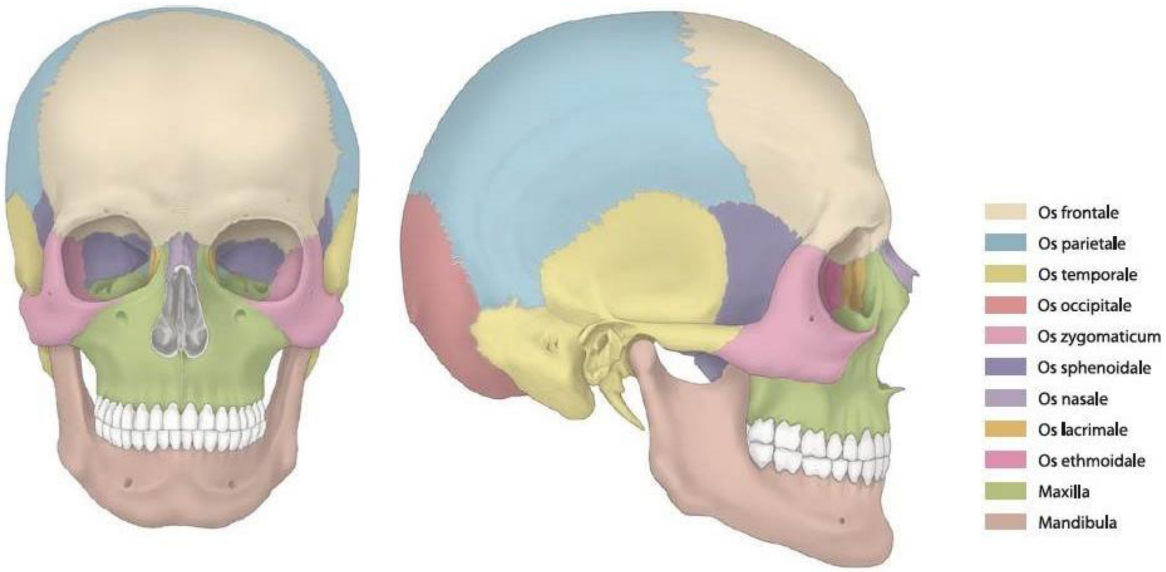


Figure 1 Facial and head (cranial) bones, neurocranium and splanchnocranium (reproduced from Tillmann 2016)

Substantially more dangerous than “isolated” osseous injuries are those involving the brain as their outcome can be potentially life-threatening. The brain is the central organ involved in the planning, initiation, execution, and regulation of almost all movements as well as important functions of life (e.g. respiratory center). Brain injuries can affect the cerebrum (telencephalon), cerebellum, diencephalon, and the brainstem (figure 2) (Bernard 2015; Trepel 2017).

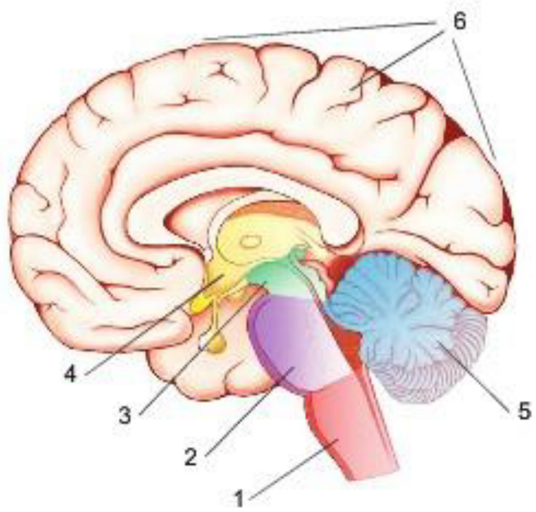


Figure 2 Main sections of the brain: brain stem (1) medulla oblongata (2) pons (3) mesencephalon (midbrain); (4) diencephalon; (5) cerebellum; and (6) cerebrum (telencephalon) (Trepel 2017)

The cerebrum is the largest and most sophisticated section of the brain. It consists of two hemispheres, separated by the fissura longitudinalis cerebri, each controlling the contralateral part of the body. There are four lobes in each hemisphere. Each lobe is responsible for specific body functions (figure 3). Depending on the affected area signs and symptoms after a head injury differ (Bernard 2015; Trepel 2017): the frontal lobe is responsible for motor control, learning, and planning; the parietal lobe for somatic and voluntary sensory; the occipital lobe for vision; and the temporal lobe for hearing and speaking. For example, frontal lobe lesions can hamper motivation and lead to behavioural and personality changes (Cazzaniga et al. 2014; Szczepanski & Knight 2014). Parietal lobe lesions can result in deficits relating to sensory feelings and spatial location (Cazzaniga et al. 2014; Freund 2003). Lesions to the temporal lobe can impair the auditory system and demonstrate failure in language processing (Cazzaniga et al. 2014), and occipital lobe lesions can cause visual disturbances (Cazzaniga et al. 2014; Ogawa et al. 2014).

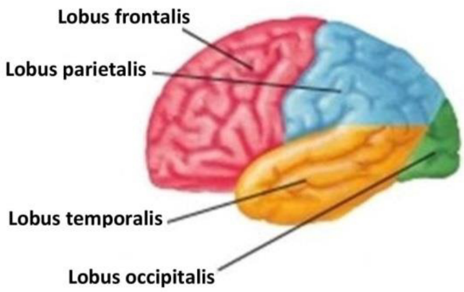


Figure 3 Structure of the cerebrum (reproduced from Netter 2015)

The diencephalon consists of the hypothalamus and the thalamus. Thus, endocrine dysfunctions (e.g. electrolyte disorders, hypopituitarism, or adrenal insufficiency) may be consequences of a traumatic brain injury affecting this part of the brain (Dusick et al. 2012; Einaudi & Bondone 2007).

The cerebellum is located caudally from the cerebrum. The main function of the cerebellum is the "fine-tuning" of voluntary movement, a prerequisite for activities of daily living as well as for sport-specific movements. More specifically, its main role is maintaining posture, allowing walking/running action, conveying information about motor outputs and sensory inputs. In the event of damage, movements can become uncoordinated (ataxia), balance disturbances may also follow (Cazzaniga et al. 2014). Furthermore, hypotonia, dysmetria, tremor, dysdiadochokinesis, and vertigo may occur (Potts et al. 2009).

The brainstem consists of three parts: the midbrain (mesencephalon), the pons varolii, and the medulla oblongata (myelencephalon). A head injury involving the brainstem can be life-threatening due to its main role in respirational control (respiratory center in the medulla oblongata) and global states of consciousness (e.g. sleep and wakefulness) (Cazzaniga et al. 2014).

2.2 Head Injuries and Associated Injury Mechanisms

Depending on the location, force, and direction of the impact, and the resulting acceleration-deceleration forces on head and brain the types of head injury differ. The following four sub-chapters provide an overview of the main/typical head injury categories prevalent in football. Furthermore, the predominant respective head injury mechanisms are presented.

2.2.1 Concussion

Concussion represents a subcategory of traumatic brain injury (TBI). Concussion may also be referred to as *'mild traumatic brain injury (mTBI)'* or *'commotio cerebri'* (McCrory et al. 2017), although there is uncertainty and inconsistency in the literature regarding definition and classification. Concussion was also described as a subset of mTBI and as an injury on the less-severe end of the brain injury spectrum (Harmon et al. 2013). The most widely used definition of concussion in sports stems from the Concussion in Sport Group (CISG), which held its 5th international conference on concussion in sport in 2016:

"Sport related concussion is a traumatic brain injury induced by biomechanical forces." (McCrory et al. 2017, p. 2)

The American Medical Society for Sports Medicine (AMSSM) published a position statement on concussion in sport and suggested the following definition:

"A concussion is defined as a traumatically induced transient disturbance of brain function and is caused by a complex pathophysiological process." (Harmon et al. 2013, p. 2)

A concussion is regarded as a so-called "functional" brain injury, in contrast to moderate to severe traumatic brain injuries that involve structural damages to the brain tissue (Harmon et al. 2013; McCrory et al. 2017). The concussion definition by the CISG includes several different features (McCrory et al. 2017):

1) Concussions are caused either by a direct blow to the head, face, neck, or elsewhere on the body with an impulsive force transmitted to the head (figure 4).
2) Concussions typically represent a rapid onset of short-lived impairment of neurological function that resolves spontaneously.

3) Concussions may result in neuropathological changes, but acute clinical symptoms reflect a functional disturbance rather than a structural injury.
4) Concussions result in a range of clinical signs and symptoms that may or may not involve loss of consciousness.

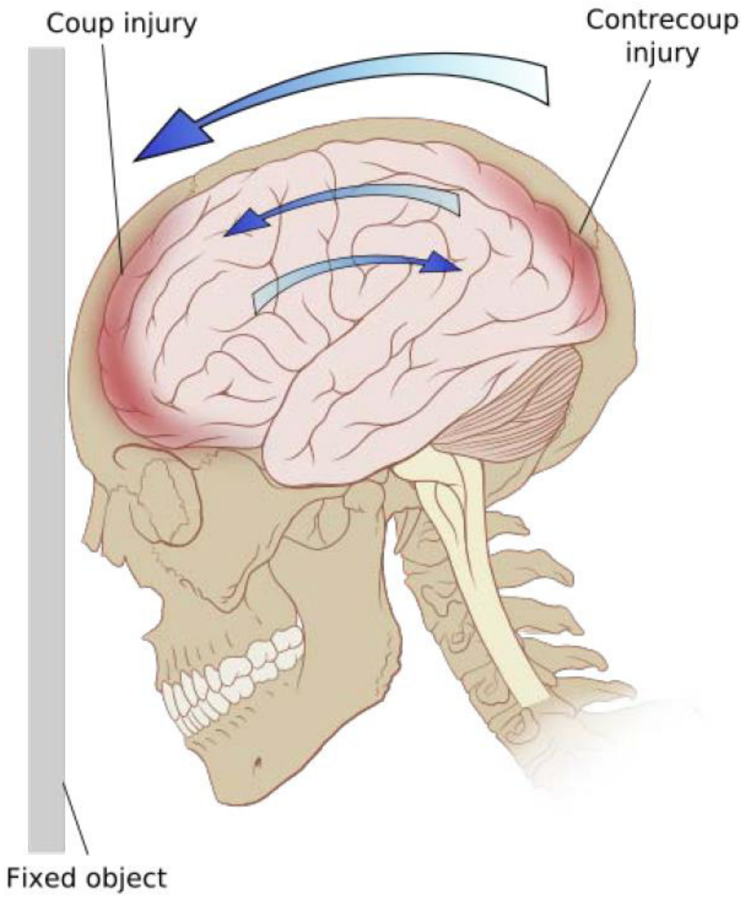


Figure 4 Head injury mechanism (e.g. concussion) with a coup (frontal lobe) and contrecoup injury (occipital lobe) as a result of acceleration-deceleration forces (Gänsslen & Schmehl 2015)

Rapid acceleration-deceleration forces to the head and brain, which can be linear, translational, and rotational, cause an immediate stretching of the axons, an increased permeability, and a disruption of neuronal membranes. These microscopic damages to the axons due to shear stress resulting in axonal disruption are called 'diffuse axonal injury' (DAI) and affect predominantly the white matter of the brain (Dashnaw et al. 2012; Khurana & Kaye 2012; Noble & Hesdorffer 2013; Vieira et al. 2016). In case DAI is apparent in a concussive injury, this may question if a concussion truly represents a so-called ‘functional’ head injury.

The pathophysiology of a concussive injury is a ‘neurometabolic cascade’, a cellular process describing ionic, metabolic, and pathophysiological events with decreased cerebral blood flow and ongoing mitochondrial dysfunction, resulting in an imbalance of energy supply and demand (Giza & Hovda 2014b; Harmon et al. 2013).

Concussed individuals often experience the following typical signs and symptoms that can affect various aspects: somatic (e.g. headache, dizziness), cognitive (e.g. feeling mentally “foggy”, feeling “slowed down”, difficulty in concentrating and remembering) and/or emotional (e.g. lability), physical (e.g. loss of consciousness, amnesia, balance problems), behavioral/emotional (e.g. irritability, sadness) and/or cognitive impairment (e.g. slowed reaction times), and/or sleep disturbance (e.g. insomnia, drowsiness) (Harmon et al. 2013; McCrory et al. 2017).

2.2.2 Head Contusions

A contusion represents a bleeding into soft tissue as a result of a rupture of small blood vessels due to a blunt trauma (Bytomski & Moorman 2010). Although the skin seems untouched, there can be haematomas under the skin (Leaper 2006). Differentiating head contusions from a concussion is somewhat difficult. Head contusions usually require less force compared to a concussion. Furthermore, head contusions represent a “local” injury with a local bruise (visible or not), whereas a concussion affects larger and often remote areas of the brain. Local pain and swelling at the site of the impact are common signs and symptoms of a head contusion (Bytomski & Moorman 2010).

2.2.3 Fractures of the Head and Face

Facial fractures in football typically involve the nasal or zygomatic bone. Substantially less frequently affected is maxilla or mandible. Head fractures are rare in football. Fractures to the frontal, parietal, sphenoidal, ethmoidal, occipital, or temporal bone have been reported (figure 1) (Goldenberg et al. 2014; Kim et al. 2016; Nilsson et al. 2013).

Facial and head fractures usually require substantial forces to the head/face. That is why they can be accompanied by intracranial injuries (and vice versa), which can vary from minor (e.g. concussion) to severe brain injuries including an intracranial hemorrhage (ICH) (Hohlrieder et al. 2003; Keenan et al. 1999; Krutsch et al. 2018; Martin et al. 2002; Pappachan & Alexander 2006). ICH is a bleeding that occurs within the intracranial vault (Freeman & Aquilar 2012). There are subtypes of ICH depending on the location of the bleeding (e.g. subdural or epidural). This bleeding can be life-threatening. Intracranial hematomas can increase the intracranial pressure, potentially limiting the blood flow to the brain causing subsequent damage to the brain tissue. They are considered to be the greatest complications of head injuries and are associated with the most fatal outcomes (Caceres & Goldstein 2012; Perel et al. 2009). They are considered as neurological emergencies as the 1-month mortality is high (35-52%). Neurosurgical intervention may be required for this kind of head injury (Freeman & Aquilar 2012). Seizures, vomiting, and/or nausea have been reported to be strong predictors for intracranial hemorrhage in patients with facial and head fractures (Hohlrieder et al. 2003).

Due to high forces involved in head and face fractures, there is an increased risk for additional (multiple) injuries and patients should be carefully examined for those accordingly. Nerve injuries (e.g. cranial nerve III) with subsequent visual and/or sensitivity disturbances must be investigated. Specifically, orbital and zygomatic bone fractures can potentially threaten vision (Reehal 2010), which requires an examination of facial symmetry (Romeo et al. 2005). The cervical spine should also be considered as cervical spine injuries are among the most devastating injuries in sports if the spinal cord and medulla are involved (Cantu et al. 2013; Schroeder & Vaccaro 2016). If the head injury results in a fall, injuries can occur (almost) anywhere.

Signs and symptoms of facial and head fractures can be very similar to those of a concussion (McCrory et al. 2017) and include amongst other things headache, swelling, dizziness, nausea, blurred vision, and balance and coordination problems (Bytomski & Moorman 2010; Krutsch et al. 2018). Furthermore, epistaxis, nasal septum haematoma, crepitus, deformity of bones, and abnormal mobility can occur (Brukner & Khan 2010).

2.2.4 Head Lacerations and Abrasions

Lacerations and abrasions are minor injuries affecting the skin (figure 5). Acute lacerations (full-thickness skin disruptions) often involve the muscular fascia (Nicks et al. 2010; Romeo et al. 2007). They typically occur when the trauma exceeds the strength and elasticity of the soft tissue, whereas abrasions represent superficial epithelial wounds (partial-thickness disruptions) caused by frictional "scraping" forces (Bytomski & Moorman 2010; Hoogenboom & Smith 2012; Leaper 2006; Romeo et al. 2007). Regardless of mechanism, lacerations and abrasions lead to an interruption of the integumentary system with damage to the small capillaries. The result is an open wound with bleeding and pain (Hoogenboom & Smith 2012).

Figure 5 Laceration (left) and abrasion (right) (reproduced from Hoogenboom & Smith 2012)

2.2.5 Head Injury Mechanisms

In contrast to muscle, joint, or ligament injuries that can occur with or without contact (Liu et al. 2012; Waldén et al. 2015), head injuries are almost always contact-related (Levy et al. 2012). The contact can be a person (opponent, team mate) or an object. Objects include the ball itself, the ground, parts of the goal (e.g. goalposts), or advertising boards if they are located close to the field (Andersen et al. 2004).

Prospective studies on head and neck injuries in football identified head to head contacts as the main cause of head injuries (approximately 30-33% of all head injuries) (Andersen et al. 2004; Delaney et al. 2006; Fuller et al. 2005; Withnall et al. 2005). The irregular use of the upper extremity is also mentioned as a significant cause (Andersen et al. 2004; Fuller et al. 2005), the most predominant being raised elbows during header duels when two players compete for the ball (Fuller et al. 2005). Delaney et al. (2006) reported that 17% of all head injuries resulted from elbow to head movements, whilst an even larger proportion of 34% was found by Andersen et al. (2004). The upper extremity (including hand and arm) caused 35% of the aforementioned injuries in the study by Fuller et al. (2005) and 38% in the study by Withnall et al. (2005), respectively.

In recent years, the debate of whether the ball itself represents a risk for head injuries in football particularly due to repetitive heading has been brought up (Baroff 1998; Kirkendall et al. 2001; Kontos et al. 2017; Maher et al. 2014; Rodrigues et al. 2016; Spiotta et al. 2012). Fuller et al. (2005) reported a low incidence rate of 0.05 per 1000 football hours for acute head injuries due to solely heading the ball. Therefore, heading as such seems to be a rather low risk activity in the light of acute head injuries. The long-term effects of repetitive heading remain to be elucidated and were not within the scope of this thesis. The same applies to the effects of heading on children's and youth football and the consequences of repeated concussions.

2.3 Complications of Concussions and Traumatic Brain Injuries

Short-term and long-term consequences can follow depending on severity and frequency of head injuries.

2.3.1 Short-Term Consequences

Concussions can result in prolonged symptoms after the initial concussion. The time frame for these "short-term" consequences is not accurately defined in the literature. Approximately 5-18% of individuals with a single episode of acute concussion are estimated to experience prolonged symptoms (Hebert et al. 2016; Makdissi et al. 2010; McCrory et al. 2013). These symptoms typically persist for more than 10 days and usually resolve within the first 4 weeks (Eisenberg et al. 2014; McCrea et al. 2013b; McCrory et al. 2013). If signs and symptoms persist longer than 4 weeks it is categorized as a "post-concussion syndrome" (PCS)

(Khurana & Kaye, 2012), which will be discussed in the next chapter (long-term consequences).

The “Second Impact Syndrome” (SIS) refers to a neurological collapse and malignant cerebral edema and swelling as a result of a second head injury with insufficient recovery after the first head injury (Cantu & Gean 2010; Giza 2014a). Return to play before all signs and symptoms are resolved is the typical scenario for an SIS to occur. In this time period there is still an increased brain vulnerability. Case reports identified the time frame for a SIS to be approximately two weeks (Cantu & Gean 2010). The SIS is believed to be caused by a loss of autoregulation of the cerebrovasculature. This dysautoregulation results in hyperemic brain swelling, which in turn increases the intracranial pressure (Cantu & Gean 2010; Cantu 2016; Giza 2014a; Hebert et al. 2016; McCrory et al. 2012). It remains speculative whether a second “full” head injury or only a subsequent minor blow is required to cause a SIS. Reports of worst case scenarios describe that individuals with SIS may appear semi-comatose with rapidly dilating pupils, loss of consciousness, and/or with respiratory failure minutes after the head injury/blow to the head (Cantu & Gean 2010; Cantu 2016; Giza 2014a; Hebert et al. 2016; McCrory et al. 2012). Accordingly, these outcomes are fatal with mortality rates of 50% and morbidity rates of 100% (Hebert et al. 2016). McCrory et al. (2012) warn that the presence of post-concussive symptoms is a significant risk factor for further head injuries.

2.3.2 Long-Term Consequences

Not only can the risk of a second head injury increase after a first head injury as short-term consequences, players also seem to be at a higher risk for other injuries in the long-term. Various studies have examined the effects of concussions on increased injury risk although the player was supposedly fully recovered from the head injury (Herman et al. 2017). Concussions were associated with an increased risk of any subsequent injury within the first year in professional football players (Nordström et al. 2014). Acute lower extremity musculoskeletal injuries were 1.5 – 3.4 times more likely to occur in college athletes (football, soccer, hockey, basketball, wrestling, volleyball, softball, and lacrosse) with a previous concussion within the previous year (Brooks et al. 2016; Herman et al. 2017; Lynall et al. 2015). The same phenomenon appeared in rugby union where injury risk increased by 60% after a concussion (Cross et al. 2016).

Deficits in neurocognitive performance and/or motor control have been discussed as factors for an increased injury risk after concussions (Herman et al. 2015). Abnormalities in brain function after concussion seem to exist beyond the point of assumed clinical recovery (Prichep et al. 2013), e.g. problems concerning coordination and postural control were detected in several studies (Buckley et al. 2013, 2016; Cavanaugh et al. 2005; Fino et al. 2016; Martini et al. 2011; Oldham et al. 2016; Sosnoff et al. 2011). Checking players on those potential deficits is not commonplace and requires more sophisticated examinations (please see chapter 2.4).

The spectrum of long-term consequences of traumatic brain injuries either caused by a single or by repetitive head traumas, mainly refers to three severe medical conditions as they represent the most clinically relevant and severe examples: the aforementioned chronic post-concussion syndrome (PCS), neurocognitive impairments (e.g. mild cognitive impairment (MCI) up to the point of dementia), and the chronic traumatic encephalopathy (CTE) (Harmon et al. 2013; Jordan 2014; Manley et al. 2017).

Post-concussion Syndrome (PCS)

Post-concussion syndrome (PCS) represents a cluster of cognitive, somatic, and emotional symptoms persisting for more than 4 weeks. They can last months or years beyond the initial concussion (Blennow et al. 2012; Khurana & Kaye, 2012; King 2014; Ryan & Warden 2003). PCS is difficult to diagnose as there are multiple differential diagnoses, therefore a detailed and multimodal clinical assessment is required (McCrory et al. 2013, 2017). Signs and symptoms can comprise headache, dizziness, insomnia, exercise intolerance, cognitive intolerance, depressed mood, irritability and anxiety, memory dysfunction, poor concentration and problem solving, fatigue, noise, and light sensitivity (King 2014; Ryan & Warden 2003). PCS can be divided into “persistent post-concussion symptoms” and “permanent post-concussion symptoms” (McCrory et al. 2013). Persistent post-concussion symptoms can last beyond three months and remain for years but disappear eventually, whereas individuals with permanent post-concussion symptoms never fully recover. The number of individuals with persistent symptoms has been estimated to be between 10-30% with up to 20% of these with permanent symptoms (Blennow et al. 2012; Hall et al. 2005; Jordan 2014; Ling et al. 2015; McCrory et al. 2013; Røe et al. 2009; Williams et al. 2010).

Neurocognitive Impairments

Neurocognitive impairments and dysfunctions can occur as neurologic sequelae of (sport-related) repetitive brain trauma (Harmon et al. 2013; Jordan 2014; Manley et al. 2017). An example for such a cognitive decline can be the mild cognitive impairment (MCI). MCI falls between the physiological cognitive changes of aging and early dementia (umbrella term for a group of symptoms such as memory loss, cognitive disability, and communicational problems) and is deemed a precursor of Alzheimer's disease (Jordan 2014; Knopman & Petersen 2014). The definite diagnosis of Alzheimer's disease is confirmed by histopathological examination via autopsy. The latter also applies to chronic traumatic encephalopathy (CTE), which is described below. However, certain clinical and cognitive criteria allow for a probable clinical diagnosis (Karantzoulis & Galvin 2011; McKhann et al. 2011). Neurocognitive impairments can be detected by neuropsychological testing (NP). Symptoms can include impaired memory, planning, and/or perceptual processing (Jordan 2014).

Chronic cognitive dysfunctions were described in active as well as in former American football athletes (Hart et al. 2013; Singh et al. 2014), active rugby players (Shuttleworth-Edwards et al. 2008; Thornton et al. 2008), former ice hockey players (De Beaumont et al. 2009), and active soccer players (Matser et al. 1999) who had a history of concussion.

Chronic Traumatic Encephalopathy (CTE)

CTE is a neurodegenerative disease as a long-term consequence of repetitive head traumas. It is characterized by a distinct tauopathy (destruction of neurons by accumulation of tau protein as neurofibrillary tangles and neuritic threads in specific areas of the brain) leading to atrophy and inflammation of the white and grey matter as well as to axonal injuries (figure 6) (DeKosky et al. 2010; McKee et al. 2013; Omalu et al. 2010; Riley et al. 2015; Stern et al. 2011). The result is a progressive decline in functioning of neurons with a subsequent neuronal death. A neuropathological classification for CTE was previously described (McKee et al. 2013): it consists of four progressive stages characterized by pathological changes ranging from normal brain weight with focal epicenters to significant reduction in brain weight with atrophy of the cerebral cortex. Although CTE is prevalent in public media, scientific and clinical knowledge about CTE remains scarce. A definitive diagnosis can solely be made postmortem through an autopsy of the brain including immunohistochemical tissue analyses (Omalu et al. 2010; Riley et al. 2015). At present there are no formal clinical diagnostic criteria for CTE (Gavett et al. 2011).

Figure 6 Pathology of CTE. A normal brain (top) with the expected size and a brain (bottom) with the characteristic pathology of CTE with severe dilatation of ventricles II (1) and III (2), of the cavum septum pellucidum (3), marked atrophy of the medial temporal lobe structures (4), and shrinkage of the mammillary bodies (5) (reproduced form Stern et al. 2011)

CTE symptoms occur years after the initial (repetitive) brain trauma(s) (Stern et al. 2011). The point in time when symptoms start is difficult to determine as there is an insidious onset and a gradual progressive course (Gavett et al. 2011). CTE is associated with cognitive impairments, depressed mood, apathy, paranoia, aggressive and irritable behavior, emotional instability, suicidal ideation, problems with impulse control, loss in orientation, memory, language and attention as well as with motor disturbances (e.g. parkinsonism) (Gardner et al. 2014a; McKee et al. 2013; Riley et al. 2015; Stern et al. 2011).

A potential relationship of sport-related head impacts and particularly (repetitive) subconcussive blows and CTE can currently not be ruled out however, the topic about sport-related causation of CTE should be approached sensitively (McCrory et al. 2017). The incidence rates in contact sports are unknown (Khurana & Kaye, 2012; Jordan 2014; Maroon et al. 2015; McCrory et al. 2017). There appears to be a substantial risk in extreme contact and collision sports such as boxing, ice hockey, rugby, and American football (Gavett et al. 2011; Jordan 2014). Nevertheless, as CTE research is presently in its infancy, a sports-specific risk assessment remains difficult if not impossible (Gavett et al. 2011).

2.4 Sideline Assessment, Diagnostic and Management of Head Injuries

Over the years, different tools have been developed in order to screen for a concussive injury. Evidence-based guidelines for injury diagnosis, evaluation, and management have been advanced. Sideline assessment at the pitch is the first and most important step in recognizing a concussion and consequently protecting an athlete from further harm (Patricios et al. 2017). Fédération Internationale de Football Association (FIFA) has recently introduced a new "concussion rule" with regards to head injuries; referees must stop matches for up to three minutes if such an injury is suspected. Following the assessment only the team doctor can decide whether an injured player is allowed to continue or not (FIFA 2014).

Significant aspects in concussion assessments are the recognition of potential signs and symptoms of concussion, a cognitive assessment, and a balance/coordination examination (McCrory et al. 2017). Aside from acute assessments during a match, further testing batteries may be useful at other time points of a season. For instance, routine neurological baseline examinations at the beginning of the season may serve as reference point as signs and symptoms can be very subtle and thus difficult to diagnose (Harmon et al. 2013). Various examinations are available, and are discussed in the following section.

Sport Concussion Assessment Tool 5 (SCAT-5)

The Sport Concussion Assessment Tool 5 (SCAT-5) is a standardized tool for evaluating injured athletes for concussions by healthcare professionals. SCAT-5 was further modified for children (Child-SCAT-5) aged 5-12 years (Davis et al. 2017). It is already the 5th version and one of the most established instruments available for sideline assessment (Echemendia et al. 2017a; McCrory et al. 2017). SCAT-5 incorporates the Maddocks' questions (Maddocks et al. 1995), the Glasgow Coma Scale (Teasdale et al. 2014), the Post-Concussion Symptom

Scale (PCSS) (Chen et al. 2007), a modified Balance Error Scoring System (BESS) (Bell et al. 2011), and the Standardized Assessment of Concussion (SAC) (McCrea et al. 1998; McCrea 2001). SCAT-5 should not solely be used to confirm or exclude the diagnosis of concussion as the results can be normal even in case of a concussion. The SCAT-5 does not evaluate all aspects that can be affected by a concussive injury (McCrory et al. 2017). That is why additional tests should be used as described below. Furthermore, linguistic difficulties might decrease its applicability. The Concussion Recognition Tool 5 (pocket version in figure 7) was created for non-medically trained individuals (Echemendia et al. 2017b).

CONCUSSION RECOGNITION TOOL 5©

To help identify concussion in children, adolescents and adults

Supported by

RECOGNISE & REMOVE

Head impacts can be associated with serious and potentially fatal brain injuries. The Concussion Recognition Tool 5 (CRT5) is to be used for the identification of suspected concussion. It is not designed to diagnose concussion.

STEP 1: RED FLAGS — CALL AN AMBULANCE

If there is concern after an injury including whether ANY of the following signs are observed or complaints are reported then the player should be safely and immediately removed from play/game/activity. If no licensed healthcare professional is available, call an ambulance for urgent medical assessment:

- **Neck pain or tenderness**
- **Double vision**
- **Weakness or tingling/ burning in arms or legs**
- **Severe or increasing headache**
- **Seizure or convulsion**
- **Loss of consciousness**
- **Deteriorating conscious state**
- **Vomiting**
- **Increasingly restless, agitated or combative**

Remember:

- In all cases, the basic principles of first aid (danger, response, airway, breathing, circulation) should be followed.
- Assessment for a spinal cord injury is critical.
- Do not attempt to move the player (other than required for airway support) unless trained to so do.
- Do not remove a helmet or any other equipment unless trained to do so safely.

If there are no Red Flags, identification of possible concussion should proceed to the following steps:

STEP 2: OBSERVABLE SIGNS

Visual clues that suggest possible concussion include:

- Lying motionless on the playing surface
- Slow to get up after a direct or indirect hit to the head
- Disorientation or confusion, or an inability to respond appropriately to questions
- Blank or vacant look
- Balance, gait difficulties, motor incoordination, stumbling, slow laboured movements
- Facial injury after head trauma

STEP 3: SYMPTOMS

- Headache
- "Pressure in head"
- Balance problems
- Nausea or vomiting
- Drowsiness
- Dizziness
- Blurred vision
- Sensitivity to light
- Sensitivity to noise
- Fatigue or low energy
- "Don't feel right"
- More emotional
- More Irritable
- Sadness
- Nervous or anxious
- Neck Pain
- Difficulty concentrating
- Difficulty remembering
- Feeling slowed down
- Feeling like "in a fog"

STEP 4: MEMORY ASSESSMENT

(IN ATHLETES OLDER THAN 12 YEARS)

Failure to answer any of these questions (modified appropriately for each sport) correctly may suggest a concussion:

- "What venue are we at today?"
- "Which half is it now?"
- "Who scored last in this game?"
- "What team did you play last week/game?"
- "Did your team win the last game?"

Athletes with suspected concussion should:

- Not be left alone initially (at least for the first 1-2 hours).
- Not drink alcohol.
- Not use recreational/ prescription drugs.
- Not be sent home by themselves. They need to be with a responsible adult.
- Not drive a motor vehicle until cleared to do so by a healthcare professional.

ANY ATHLETE WITH A SUSPECTED CONCUSSION SHOULD BE IMMEDIATELY REMOVED FROM PRACTICE OR PLAY AND SHOULD NOT RETURN TO ACTIVITY UNTIL ASSESSED MEDICALLY, EVEN IF THE SYMPTOMS RESOLVE

Figure 7 Pocket Concussion Recognition Tool 5 (McCrory et al. 2017)

Computerized neurocognitive testing tools

Commercially available, computerized neurocognitive testing tools such as the Immediate Post-concussion and Cognitive Testing (ImPACT), the Automated Neuropsychological Assessment Metric (ANAM), the CNS-Vital Signs (CNS-VS), or the Axon/CogState/CogSport (CogState) have become popular among clinicians evaluating sport-related concussions (Alsalaheen et al. 2016; Arrieux et al. 2017; Cole et al. 2018; Covassin et al. 2009).

ImPACT is an instrument for the objective measure of neurocognitive functioning and consists of a neuropsychological screen with four composite scores including verbal memory, visual memory, visual-motor processing speed, and reaction time (Alsalaheen et al. 2016; Gaudet & Weyandt 2017). ANAM was originally developed for military purposes and is a measure of cognitive performance. It measures accuracy and processing speed as well as cognitive efficiency to evaluate cognitive performance (Levinson et al. 2005; Vincent et al. 2012). CNS-VS was developed as a routine clinical screening instrument and it is comprised of seven tests: verbal and visual memory, finger tapping, symbol digit coding, the Stroop Test, a test of shifting attention, and the continuous performance test (Gualtieri & Johnson 2006). CogState was specifically developed for repeated testing of individuals and measures a wide range of cognitive functions (e.g. psychomotor speed, reaction time, working memory, divided attention, learning) (Falleti et al. 2006; Louey et al. 2014). Each computerized neurocognitive testing tool can be administered in approximately in 25-30 minutes.

Balance and coordination testing tools

Besides the aforementioned tests, there are a variety of tools addressing various isolated aspects of concussions such as balance and coordination. These tests can be conducted to gather further information if other tests show inconclusive results with regards to a diagnosis of concussion. The BESS, which is already included in SCAT-5, is a cost-effective method to assess static postural stability and consists of different stances (Bell et al. 2011). The King-Devick test is an objective tool, which consists of rapid number naming and can be conducted in 1-2 minutes. This task requires the coordination of multiple cortical and subcortical pathways of the brain (especially the dorsolateral prefrontal cortex) and brainstem, areas, which are often impaired after a concussion (Galetta et al. 2011; Okonkwo et al. 2014).

Furthermore, various cost-efficient and not cost-efficient laboratory tests are helpful in detecting balance dysfunctions. For instance, the clinical test of sensory organization and balance (CTSIB) is a low-technology and subjective test and relies upon trained rater interpretations of balance deficits (Murray et al. 2014). In addition, the sensory organization test (SOT) uses laboratory equipment (moving platform) to assess balance performance (Murray et al. 2014), whilst the vestibular-ocular-motor screening test (VOMS) includes assessments of the vestibulo-ocular and ocular motor function (Mucha et al. 2014).

Additional neurological tests or diagnostic imaging are recommended if less sophisticated tests are inconclusive, if a more severe injury is suspected, and/or to exclude further injuries. Cranial magnetic resonance imaging (MRI) can exclude a structural brain injury (Giza et al. 2013; Harmon et al. 2013; McCrory et al. 2017). Orthopedic examinations can be conducted, e.g. for cervical spine dysfunction. A psychological evaluation can reveal affective disorders such as depression, irritability, and anxiety (Feddermann-Demont et al. 2014; McCrory et al. 2017; Romeo et al. 2007).

Diagnostic imaging

At present, evidence-based diagnostic procedures in a clinical setting to detect concussions are still scarce. Standard routine neuroimaging such as computed tomography (CT) and MRI have been described as being ineffective in the diagnosis of sport-related concussion (Pulsipher et al. 2011). This is not surprising as concussions seem to represent functional rather than structural damages to the brain. However, the damage after concussion could lie beyond the resolution of the current “structure-based” scanning technologies (Gao & Chen 2011). Nevertheless, CTs and MRIs are useful in detecting hemorrhages or skull fractures (Kutcher et al. 2013). Standard neuroimaging techniques may also be helpful in monitoring chronic alterations (e.g. neurodegeneration) of the brain following the head injury (Bigler 2013).

Neurophysiological imaging examinations

Some established methods are able to visualize brain physiology, metabolism, and activity with special techniques. They may be helpful in the future to objectify concussions and brain injuries or dysfunctions with and/or without obvious structural damage currently classified as "functional". Experimental techniques that could become promising are:

1) Functional magnetic resonance imaging (fMRI) to visualize activity pattern of impaired networks (Chen et al. 2004; Jantzen et al. 2004; Slobounev et al. 2010; Talavage et al. 2014)

2) Diffusion tensor imaging (DTI) to detect white matter injury and structural damage to brain networks (Gardner et al. 2012; Inglese et al. 2005; Li et al. 2016; Mayer et al. 2010; Xu et al. 2007)

3) Magnetic resonance spectroscopy (MRS) to detect pathophysiological processes and energy expenditure of the brain (Gardner et al. 2014b)

4) Single photon emission computed tomography (SPECT) to show brain metabolism and cerebral perfusion (Hofman et al. 2001; Kutcher et al. 2013; Lewine et al. 2007; Lorberboym et al. 2002)

5) Quantitative electroencephalography (qEEG) to record electrical activity and to detect pathology or deviation from the norm (McCarthy & Kosofsky 2015; McCrea et al. 2013a)

6) Magnetoencephalography (MEG) to record magnetic fields produced by the brain's electrical activity (Dunkley et al. 2015; Huang et al. 2014; Kutcher et al. 2013; Lee & Huang 2014; Pang et al. 2016)

2.5 Treatment, Recovery and Return to Play from Head Injury

Depending on the diagnosis, the severity, and the treatment duration of head injury recovery varies widely. For concussions, specific treatment strategies were developed over the years (figure 8). In general, (relative) physical and cognitive rest are the predominant recommendation post-injury, at least until the acute symptoms resolve (Brown et al. 2014; Johnson et al. 2017; McCrory et al. 2017; Moser et al. 2012). Rest may be effective in mitigating post-concussion symptoms, promoting recovery by minimizing energy demands during haemodynamic and neurometabolic restoration, and minimizing the risk for another head injury within the first 7-10 days after the initial concussion (Schneider et al. 2017). Nevertheless, the exact extent and duration of rest is yet not well defined in the literature. Following a brief period of (relative) rest during the acute phase after the concussion, players may become gradually and progressively more active. Staying below their cognitive and physical symptom-exacerbation thresholds while progressing seems mandatory (McCrory et al. 2017).

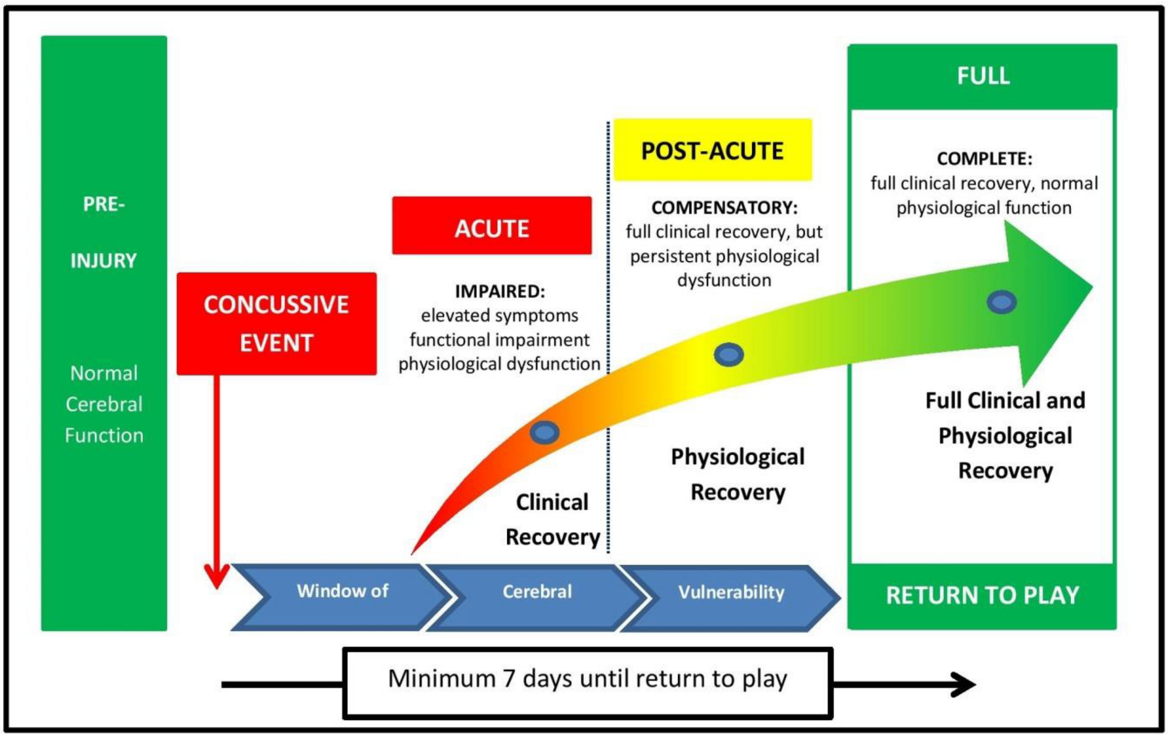


Figure 8 Clinical and physiological recovery after concussion (reproduced from McCrea et al. 2015)

Return to play after sustaining a concussion is recommended 7 days at the earliest (McCrory et al. 2017). However, symptoms may persist for longer (Harmon et al. 2013; McCrea et al. 2013b). A medical clearance for return to play should be mandatory. Return to play is only recommended when the player is asymptomatic and neurological examinations are unremarkable again (Feddermann-Demont et al. 2014; Levy et al. 2012). Neurological examinations should include a thorough assessment of mental status, cognitive functioning, sleep/wake disturbances, ocular and vestibular function, gait and balance (chapter 2.4) (Feddermann-Demont et al. 2014; McCrory et al. 2017).

The consensus statement of concussion in sports presents a graded return to play protocol with a stepwise progression (McCrory et al. 2017). This protocol is outlined in figure 9. Each step lasts 24 h. Athletes are allowed to proceed to the next level if asymptomatic at the current level. Therefore, a full rehabilitation lasts at least 7 days. Similar concussion guidelines were previously published by the Australian Rugby Union (ARU), the National Football League (NFL), and the Football Association in England (FA). Nevertheless, these protocols may not always be appropriate for each athlete. Younger athletes, those with prolonged symptoms, or athletes with repetitive concussions require an individualized return to play decision (Sabini et al. 2014).

Stage	Aim	Activity	Goal of each step
1	No activity	Symptom limited rest →Physical (no exercise) →Cognitive (no TV, PC, gaming or intensive reading)	Recovery
2	Light aerobic exercise	→Walking or stationary cycling at slow to medium pace →No resistance training	Activation of cardiovascular circulation
3	Football-specific exercise	Individualized training →Running drills →No head impact activities	Football-specific movement and coordination skills
4	Non-contact training drills	→More complex training drills (e.g. passing drills) and explosive movements →May start progressive resistance training →Progression from aerobic to anaerobic exercises	Increase of exercise, coordination, and cognitive load
5	Return to routine training	Following medical clearance →Participation in normal training activities	Restoration of confidence and assessment of functional skills by coaching staff
6	Return to play	Normal game play	

Figure 9 Graded return to play protocol (reproduced from Feddermann-Demont et al. 2014; McCrory et al. 2017)

2.6 Aims of the PhD-Thesis

The aim of this thesis is to examine head injuries in male football players of the 1st German league (Bundesliga). This work presents epidemiological data, investigates head injury mechanisms, and the effect of prevention measures to reduce head injuries over the duration of 17 seasons (2000/01 – 2016/17). In this regard, the present data aims to close the scientific gap on head injuries in football in Germany.

Study 1 examined the time trends of head injuries starting in season 2006/07 after introducing the new rule; intentional elbow to head contacts were punishable by a red card. The aim was to evaluate the variation of head injury incidence rates and their injury mechanisms in the 11 subsequent seasons (up to season 2016/17). **Study 2** analyzed match situations in order to identify actions in football that are associated with head injury occurrence. Furthermore, the behavior of referees and their decisions in case of head injuries were part of the video-based analyses. Finally, **study 3** investigated head injury incidence rates and their predominant injury mechanisms. Furthermore, the effect of the rule change in 2006 with regards to injury prevention was examined by comparing six seasons before and six seasons after the rule change.

2.7 Data Collection and Statistical Approaches

The 17-year database for analyzing head injury incidence rates, injury mechanisms, match situations, and effects of the rule change was created by a structured search through online media. The main source was the German football magazine 'kicker Sportmagazin®'. This magazine offers print and online issues and is published twice a week. One journalist is responsible for one club with daily contact to respective club officials (press offices). The magazine contains injury reports and summaries of each match. The online versions also offer the opportunity for a free text search. Search terms were: concussions; (mild) traumatic brain injury; contusion; fracture, laceration; abrasion; face; head; brain; neck; skull; cranium; zygomatic bone; mandible; maxilla; nose; eye.

In addition to the main head injury types (concussion/TBI, head contusions, fractures of the head and face, head lacerations/abrasions) a new subgroup 'suspected concussions' was created (**study 3**). Fractures of the zygomatic bone and skull (e.g. base of the skull, calvaria, and frontal sinus) as well as head contusions (to the skull and zygomatic bone only) were added to this subgroup. The rationale was that substantial force is required to cause a facial fracture and this could also be associated with an intracranial injury (Keenan et al. 1999; Pappachan & Alexander 2006). Additionally, differentiating head contusions from a concussion is somewhat difficult. Therefore, concussions could have been diagnosed as head contusions only. Injuries affecting the nasal bone (fractures, contusions), mandibular fractures, and head/face lacerations/abrasions were excluded from that category as such injuries may not necessarily transmit the force of impact directly to the cranium and the brain, respectively. But, certain lacerations and abrasions (if located directly on the skull) might be forceful enough to cause concussions and may also be classified as minor intracranial injuries. Conversely, injuries retrospectively assigned to the category 'suspected concussion' might not have resulted in concussion-like impairments. Injuries with an unclear description and unknown diagnosis were categorized as 'other head injury'. In case an injury encompassed more than one diagnosis, the more severe injury was recorded.

This thesis did not include training injuries. Head injury rates in football training were reported considerably low compared to matches (Ekstrand et al. 2013). Nilsson et al. (2013) reported a 38-fold higher rate of head injuries and even 78-fold higher rate of concussions in football matches. The recent systematic review by Prien et al. (2018) confirmed that head injuries, and concussions, were rare in football training.

The severity of injuries was based on the time loss according to the consensus statement published 2006 (Fuller et al. 2006). Severity is categorized as slight (time loss 0 days), minimal (1–3 days), mild (4–7 days), moderate (8–28 days), and severe (>28 days). For those injuries with an unknown outcome (e.g. towards the end of the season), the mean time loss for the particular diagnosis in the aforementioned database was considered.

Data of the seasons 2000/01 – 2013/14 were exclusively collected via kicker. Data of the seasons 2014/15 – 2016/17 were additionally collected using: web pages (transfermarkt.de, ligainsider.de), social media channels of the players and teams (Twitter, Facebook, and Instagram), team homepages and newsletters, TV sports channels (e.g. Sky Sports News), and local newspapers.

Video recordings of each match head injury were obtained from the official German Football League ("Die Liga – Fußballverband (DFL)") and wyscout®. Analyzed aspects were: injury causation, injury mechanism, point of contact on the injured player's head/neck, tackle direction, action performed by the non-injured and injured player, foul (referee decision, additional assessment by a football experienced sports scientist), injured player aware of imminent impact, ball possession status at the time of the incident, bleeding as consequences of the head impact, and on-pitch treatment (first aid measures).

The following official games were included in the analysis: all domestic season games, cup games (DFB-Cup, League Cup, Super-Cup) and international games, which included German teams (Champions League, Europe League, UEFA-Cup, Ui-Cup). Extra time in knock-out games was also considered. Games of the national teams were not included. Match exposure was calculated using the following calculation (Fuller et al. 2006):

Number of official games x number of players on the field (22 players) x duration of the game in hours (1.5 hours for a regular game, 2 hours for games with overtime)

Incidence rates (IR) and 95% confidence intervals (CI) were calculated with the following formulas (Hägglund et al. 2006):

Incidence = (number of injuries/hours of match exposure) × 1000

Lower 95% CI = Incidence / e1.96 x (square root [1/number of incidents])

Upper 95% CI = Incidence * e1.96 x (square root [1/number of incidents])

Incidence rate ratios (IRR) and chi-square test (χ^2) were used to assess differences between various time periods in **study 2** and **3** (seasons 2000/01-2005/06 and 2007/08-2012/13). Time trends (**study 1**), expressed as the average annual percentages of change, were analysed using a linear regression model with the log-transformed IR as the dependent variable (Ekstrand et al. 2013; Hägglund et al. 2016).

3 Study Overview

3.1 Study 1: Time trends of head injuries over multiple seasons in professional male football (soccer)

Beaudouin F, aus der Fünten K, Tröß T, Reinsberger C & Meyer T

Sports Medicine International Open 2018; Accepted on Nov 13.

Introduction: To investigate time trends of head injuries and their injury mechanisms since a rule change as monitoring may help to identify causes of head injuries and may advance head injury prevention efforts.

Methods: Based on continuously recorded data from the German football magazine "kicker Sportmagazin®" as well as other media sources, a database of head injuries in the 1st German male Bundesliga was generated comprising 11 consecutive seasons (2006/07-2016/17). Injury mechanisms were analysed from video recordings. Injury incidence rates (IR) and 95% confidence intervals (95% CI) were calculated. Time trends were analysed via linear regression.

Results: 238 match head injuries occurred (IR 1.77/1000 match hours, 95% CI 1.56-2.01). There were no significant seasonal changes, expressed as annual average year on year change, in IRs over the 11-year period for total head injuries (p=0.693), facial/head fractures (p=0.455), lacerations/abrasions (p=0.162), and head contusions (p=0.106). The annual average year on year increase for concussion was 6.4% (p=0.004). Five head injury mechanisms were identified. There were no seasonal changes in injury mechanisms over the study period.

Discussion: The subcategory concussion increased slightly over the seasons which may either be a result of increasing match dynamics or raised awareness among team physicians and players.

3.2 Study 2: Match situations leading to head injuries in professional male football (soccer) – a video-based analysis over 12 years.

Beaudouin F, aus der Fünten K, Tröß T, Reinsberger C & Meyer T

Clinical Journal of Sports Medicine 2018; Jan 19. doi: 10.1097/JSM.0000000000000572. [Epub ahead of print]

Introduction: In order to prevent head injuries in professional football, it is necessary to know typical circumstances of such incidents, e.g. the players' actions on the pitch immediately preceding the head injury and the ball possession status. Additionally, the impact of a rule change in 2006 punishing elbow-head contacts was investigated.

Methods: A retrospective (video) analyses of head injuries was conducted in professional football players of the 1. German "Bundesliga". Based on continuously recorded data from the German football magazine "kicker Sportmagazin®", a database of all head injuries was generated comprising seasons 2000/01-2012/13. Head injuries of official games were analysed from video recordings. This study describes and assesses circumstances immediately preceding head injuries in professional male football. Injury incidence rate (IR) and 95% confidence intervals (95% CI) for total head injuries were calculated. Chi-square analyses were performed to determine differences between the two time periods.

Results: 334 head injuries were reported in 'kicker Sportmagazin®' corresponding to an IR of 2.25 (95% CI 2.01-2.51) per 1000 match hours. The injured player predominantly jumped (60%), headed the ball (36%) or ran forwards (20%); the non-injured players mainly jumped (64%), headed the ball (27%) or raised the elbow to the head (23%). Free ball situations (two players challenge for the ball) caused most of the head injuries (81%). The players' action "raising the elbow" during a head injury seemed to be lower after the rule change.

Discussion: Jumping for the ball with the intention of heading is the predominant action associated with head injury risk. Head injuries occur most often when players challenge for the ball in a header duel. As head injuries bear the potential risk of long-term health sequelae, the identification of situational circumstances is essential to develop preventative means in the future.

3.3 Study 3: Head injuries in professional male soccer over 13 years – 29% lower incidence rates after of a rule change (red card)

Beaudouin F, aus der Fünten K, Tröß T, Reinsberger C & Meyer T

British Journal of Sports Medicine 2017; June 23. doi: 10.1136/bjsports-2016-097217. [Epub ahead of print]

Introduction: Although the incidence of head injuries in football is relatively low in comparison to American football, rugby or ice hockey, absolute numbers are considerable because of its high popularity and the large number of players. In 2006, a rule was altered (red card in case of intentional elbow to head contact) to reduce head injuries. This study provides a description of injury mechanisms of head injuries and examines the effect of the rule change.

Methods: Based on continuously recorded data from the German football magazine “kicker”, a database of all head injuries in the 1st German Male Bundesliga was generated comprising seasons 2000/01–2012/13 with a free-text search with defined search terms. Injury mechanisms were analysed from video recordings. Injury incidence rates (IR) and 95% confidence intervals (95% CI) as well as incidence rate ratios (IRR) to assess differences before and after the rule change were calculated.

Results: 356 head injuries were recorded (IR 2.22 (95% CI, 2.00–2.46) per 1000 match hours). Contact with another player caused most head injuries, more specifically because of head to head (34%) or elbow to head (17%) contacts. After the rule change head injuries were reduced by 29% (IRR 0.71, 95% CI, 0.57–0.86, p=0.002). Lacerations and abrasions declined by 42% (IRR 0.58, 95% CI, 0.39–0.85, p=0.006), concussions by 29% (IRR 0.71, 95% CI, 0.46–1.09, p=0.12), contusions by 18% (IRR 0.82, 95% CI, 0.43–1.55, p=0.54) and facial fractures by 16% (IRR 0.84, 95% CI, 0.55–1.28, p=0.42).

Discussion: The present study shows that the incidence rate for head injuries and their most frequent mechanisms head-head and elbow-head were lower in the seasons after the rule change. Rule changes in football seem to be appropriate means to achieve a reduction of head injuries.

4 Summary and Discussion of Findings

Head injuries in sports bear the risk of serious acute and long-term consequences (Harmon et al. 2013; Levy et al. 2012). This debate has reached football as heading the ball is a football-specific element, in which players intentionally deflect, stop, or redirect the ball (Spiotta et al. 2012). Therefore, football players may also be at an increased risk for head injuries, for instance due to potential collisions (head to head contacts, elbow to head contacts etc.) with other players (Andersen et al. 2004; Fuller et al. 2005; Levy et al. 2012). Absolute numbers of head injuries are substantial because of the high popularity of this sport and the large number of active players worldwide and in Germany alike. However, injury data on head injuries in German football have been scarce. Therefore, this PhD-thesis aimed to provide incidence rates and injury mechanisms of head injuries in German male professional football. Furthermore, it investigated the effect of a rule change as preventative measure.

The results of the studies within this thesis provide further evidence that the incidence of head injuries is rather low compared to so-called high risk sports such as American football, rugby, or ice hockey (Cross et al. 2016; Donaldson et al. 2013; Zuckermann et al. 2015). The first step when comparing incidence rates of (head) injuries in the literature is to ascertain, which exposure time was considered, match and/or training time as rates differ considerably. The UEFA Champions League study is an ongoing injury surveillance study in professional male football that started in 2002. The first publication from this project reported an overall head injury incidence rate of 0.32 per 1000 football hours (Waldén et al. 2005). A 7-year follow-up then identified a head injury incidence rate of 0.14 per 1000 football hours (Ekstrand et al. 2011). Both studies reported the overall head injury rate, thus including training and match injuries alike. These numbers are considerably lower compared to the numbers presented in this thesis (IR 1.77 in **study 1** and IR 2.22 in **study 3**), which included match injuries only. Head injury incidence rates between 0.70 and 1.70 per 1000 match hours have been reported in the last years (Andersen et al. 2004; Bjørnboe et al. 2013, 2014; Carling et al. 2010; Kristenson et al. 2013; Nilsson et al. 2013; Stubbe et al. 2015). The highest number of head injuries was reported during FIFA World Cup tournaments. Fuller et al. (2005) reported an incidence rate of head injuries of 12.5 per 1000 match hours with regards to 20 FIFA international tournaments over the period 1998 – 2004. Head injury data comprising all FIFA World Cups, FIFA Confederations Cups, and Olympic football tournaments during 1998 to 2012 showed an almost equal incidence rate of 11.3 per 1000 match hours (Junge & Dvorák

2013). The FIFA World Cup 2014 revealed an incidence rate of 9.3 per 1000 match hours (Junge & Dvorák 2015).

It appears apparent that it is rather difficult to compare head injury data from international tournaments with head injury data from regular league activity. A potential, but rather speculative explanation for higher (head) injury rates might be a higher intensity and importance of each game during such tournaments (low number of games, knock-out rounds etc.). But even head injury data from the different aforementioned studies that cover (mainly) league activities differ slightly and are up to three times lower compared to the present data within this thesis. This may be caused by different approaches with regards to collecting (head) injury data. One common approach to collecting injury data is through media sources. For instance, the German football magazine 'kicker Sportmagazin®' is published twice a week with one journalist being responsible for one club and usually having contact with the press offices of the club every day. This level of investigation and depth of media coverage should allow for adequate data collection and therefore, the present analysis appears to be fairly complete. Nonetheless, the journalists responsible for data collection may not always record (and/or be aware of) all head injuries, specifically, not the minor injuries. This would be very desirable as minor repetitive head injuries could result in more severe head injuries.

Online sports databases have previously been used to gather information on injuries in professional German football (Leventer et al. 2016). Leventer et al.'s data on head injury rates were lower compared to the present results (Head injury IR for seasons 08/09 – 13/14: 0.61 versus 1.90/1000 match hours). The number of recorded head injuries was lower and the match exposure calculations differed. Thus, it seems that relying on 'transfermarkt.de' as the sole data source is insufficient with regards to (head) injury recording. On the contrary, although media-based data collection (kicker Sportmagazin®, transfermarkt.de etc.) provides enormous potential, these data are not validated with medical records by each team's medical departments. This does not seem surprising as football teams do not intend to share sensitive data with media. Diagnoses obtained from medical records are the gold standard for research purposes (Andersen et al. 2004; Bjørnboe et al. 2013; Ekstrand et al. 2011; Fuller et al. 2005; Junge & Dvorák 2013, 2015; Nilsson et al. 2013; Waldén et al. 2005). The clear advantage is the accuracy and quality of such data as full-time football players are seen daily by their medical staff. That also allows for precise capturing of exposure time, injury and time loss recordings, respectively. However, these approaches require the collaboration with the teams' medical officials. But even under those presumably "perfect" circumstances, there is no guarantee of data integrity. Bjørnboe et al. (2011) found that medical staff reports underestimated the incidence of time-loss injuries by up to 20%. Nevertheless, the combination of different media sources in this thesis fairly allows for a realistic assumption of the proportion of head injuries.

Although media sources provided diagnoses for all head injuries, their accuracy should be interpreted with caution as the diagnosis is often made by non-medical professionals. Furthermore, head injuries can be accompanied by further injuries. Often only the (presumably) most severe injury is reported. Moreover, diagnosing concussions is particularly challenging (McCrory et al. 2017). Concussions can easily be overlooked by non-medical professionals, inexperienced medical staff, and even highly qualified medical staff due to mild symptoms or even trivialized post-injury symptoms by the player himself (Broglio et al. 2010; Feddermann-Demont et al. 2014; Khurana & Kaye 2012; Levy et al. 2012; Meehan et al. 2013; Meier et al. 2015; Putukian et al. 2009; Williamson et al. 2006). Additionally, their signs and symptoms can rapidly change and disappear (McCrory et al. 2017). As a consequence players with concussion or TBI symptoms are often diagnosed as head contusion only. Concussions are considered to be one of the most complex injuries in sports medicine to diagnose, assess, and manage. To date there is no perfect diagnostic test or marker for the immediate diagnosis of concussion (McCrory et al. 2017). It is likely that the estimated number of head injuries, particularly concussions, is somewhat higher as some injuries might go underreported or wrongly diagnosed, respectively. According to this, the exact number of concussions in professional sports including football is still unknown. Studies estimate that up to 30% of all concussions remain undiagnosed (Meehan et al. 2013; Meier et al. 2015; Williamson et al. 2006).

In case of concussion, current consensus recommendations emphasize a sufficient (relative) rest and recovery period (McCrory et al. 2017), but it seems that half of the concussed players in this database returned to play in less than the recommended one week and consequently, some players may have returned to play prematurely following concussion. This may enhance the risk for further consequences such as Second Impact Syndrome (Cantu & Gean 2010; Cantu 2016; Giza 2014a; Hebert et al. 2016; McCrory et al. 2012).

Video material served as data source for the identification of head injury mechanisms. In this analysis (17 seasons) 84% of the head injuries were available on video recordings. The high coverage is excellent compared to previous studies. Tscholl et al. (2007) could identify 80%

of their head injuries on video recordings, whilst other video analysis-based studies identified approximately 66% (Fuller et al. 2005) and 65% (Andersen et al. 2004). The high number of video evidence can be regarded as strength of this thesis. According to the videos, the majority of head injuries were contact-related either with the opponent or the team mate. In particular, head to head contacts as well as elbow to head contacts were deemed responsible for most of the head injuries in this thesis (**study 1, 2 and 3**). Furthermore, jumping with the intention of heading could be detected as specifically head injury prone (**study 2**). Previously published data confirm these results (Andersen et al. 2004; Delaney et al. 2006; Fuller et al. 2005; Withnall et al. 2005). In addition, head to head contacts have previously been mentioned to be the predominant injury mechanism for the causation of head injuries (Fuller et al. 2004; Nilsson et al. 2013). The introduction of a straight red card for direct and deliberate elbow to head contacts in 2006 was a logical step following on from studies published by Andersen et al. (2004) and Fuller et al. (2005). This preventative measure appeared to be effective in reducing the number of head injuries that occurred due to elbow to head movements (-23%) (**study 2 and 3**) and the number of head injuries in general (-29%) (**study 3**). Players and coaches might have had a raised awareness of these head injury mechanisms and the potential severe consequences since the rule change further contributing to the lower incidence of these incidents.

5 Future Research and Directions

The ongoing aim remains reducing head injuries to the greatest possible extent. The rule change from 2006 (punishing elbow to head movements) was a first step in reducing head injuries as it penalized one of the core injury mechanisms. However, further steps will have to follow.

As header duels and jumping were deemed the main actions causing head injuries in this PhD-thesis, a logical step in the light of head injury prevention from a medical point of view would be banning these football-specific features from the game. But undoubtedly, this is a significant change to the rules and nature of football, which is unlikely to be considered. Another approach with greater feasibility could be the use of protective equipment. Professional (Petr Cech, Arsenal FC) and semi-professional players (Klaus Gjasula, Hallescher FC) have already reacted after suffering from head injuries in the past by wearing protective helmets, with similar properties to scrum caps commonly seen in rugby union. To date however, the evidence for a protective effect has not been demonstrated (Harmon et al. 2013; Levy et al. 2012; Niedfeldt 2011). Furthermore, convenience and acceptance of the players might play a role in the prevalence of their future use.

Equally important as diminishing the number of head injuries is improving the accuracy in diagnosing and managing concussions. The FIFA has introduced a "concussion rule" with regards to head injuries: referees can stop matches for up to three minutes; the team doctor only can decide whether an injured player is allowed to continue or not (FIFA 2014). This rule could be advanced similar to the NFL's "concussion safety protocol" (NFL 2014): this protocol requires players to be examined precisely at the sideline if necessary followed by further investigation in the locker room. Therefore, special observers ("spotters") and "unaffiliated neurotrauma consultants" have to be present during each match and report potential concussions (with the help of video analyses) to team doctors and team coaches. Whilst this rule was not designed to prevent concussions, it may help to diagnose these injuries accurately and to prevent players from further harm (e.g. Second Impact Syndrome). Such a rule could be implemented in football to raise further awareness and recognition of concussions. Another possibility would be to screen players prior to the sports activity for modifiable risk factors (e.g. fatigue, prior concussion, excessive post-injury exercise), which could increase the injury risk, although this would mean an enormous challenge for the medical staff and coaches. Nevertheless, this approach could help to design, implement, and evaluate appropriate training interventions to reduce the risk of head injuries (Finnoff et al. 2011; Harmon et al. 2013).

6 References

1. Alsalaheen B, Stockdale K, Pechumer D, Broglio SP. Validity of the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT). Sports Med 2016; 46: 1487-1501.

2. Andersen TE, Arnason A, Engebretsen L, Bahr R. Mechanisms of head injuries in elite football. Br J Sports Med 2004; 38: 690-696.

3. Arrieux JP, Cole WR, Ahrens AP. A review of the validity of computerized neurocognitive assessment tools in mild traumatic brain injury assessment. Concussion 2017; 2: 1-23.

4. Baroff GS. Is heading a soccer ball injurious to brain function? J Head Trauma Rehabil 1998; 13: 45-52.

5. Beckwith JG, Greenwald RM, Chu JJ, Crisco JJ, Rowson S, Duma SM, Broglio SP, McAllister TW, Guskiewicz KM, Mihalik JP, Anderson S, Schnebel B, Brolinson PG, Collins MW. Head impact exposure sustained by football players on days of diagnosed concussion. Med Sci Sports Exerc 2013a; 45: 737-746.

6. Beckwith JG, Greenwald RM, Chu JJ, Crisco JJ, Rowson S, Duma SM, Broglio SP, McAllister TW, Guskiewicz KM, Mihalik JP, Anderson S, Schnebel B, Brolinson PG, Collins MW. Timing of concussion diagnosis is related to head impact exposure prior to injury. Med Sci Sports Exerc 2013b; 45: 747-754.

7. Bell DR, Guskiewicz KM, Clark MA, Padua DA. Systematic review of the balance error scoring system. Sports Health 2011; 3: 287-295.

8. Bernard SP (2015). Netter's Atlas of Surgical Anatomy for CPT Coding (1st edition). American Medical Association, USA.

9. Bigler ED. Traumatic brain injury, neuroimaging, and neurodegeneration. Front Hum Neurosci 2013; 7: 1-15.

10. Bjørnboe J, Flørenes TW, Bahr R, Andersen TE. Injury surveillance in male professional football; is medical staff reporting complete and accurate? Scand J Med Sci Sports 2011; 21: 713-720.

11. Bjørnboe J, Bahr R, Dvorák J, Andersen TE. Lower incidence of arm-to-head contact incidents with stricter interpretation of the Laws of the Game in Norwegian male professional football. Br J Sports Med 2013; 47: 508-514.

12. Bjørneboe J, Bahr R, Andersen TE. Gradual increase in the risk of match injury in Norwegian male professional football: a 6-year prospective study. Scand J Med Sci Sports 2014; 24: 189-196.

13. Blennow K, Hardy J, Zetterberg H. The neuropathology and neurobiology of traumatic brain injury. Neuron 2012; 76: 886-99.

14. Broglio SP, Vagnozzi R, Sabin M, Signoretti S, Tavazzi B, Lazzarino G. Concussion occurrence and knowledge in Italian football (soccer). J Sports Sci Med 2010; 9: 418-430.

15. Brooks MA, Peterson K, Biese K, Sanfilippo J, Heiderscheit BC, Bell DR. Concussion Increases Odds of Sustaining a Lower Extremity Musculoskeletal Injury After Return to Play Among Collegiate Athletes. Am J Sports Med 2016; 44: 742-747.

16. Brown NJ, Mannix RC, O'Brien MJ, Gostine D, Collins MW, Meehan WP 3rd. Effect of cognitive activity level on duration of post-concussion symptoms. Pediatrics 2014; 133: 299-304.

17. Brukner P, Khan K (2010). Clinical Sports Medicine (3rd edition). McGraw-Hill, Australia.

18. Buckley TA, Munkasy BA, Tapia-Lovler TG, Wikstrom EA. Altered gait termination strategies following a concussion. Gait Posture 2013; 38: 549-551.

19. Buckley TA, Oldhama JR, Caccese JB. Postural control deficits identify lingering post-concussion neurological deficits. J Sport Health Sci 2016; 5: 61-69.

20. Bytomski JR, Moorman CT (2010). Oxford American Handbook of Sports Medicine (1st edition). University Press, Oxford New York.

21. Caceres JA, Goldstein JM. Intracranial Hemorrhage. Emerg Med Clin North Am 2012; 30: 771-794.

22. Cantu RC, Gean AD. Second-impact syndrome and a small subdural hematoma: an uncommon catastrophic result of repetitive head injury with a characteristic imaging appearance. J Neurotrauma 2010; 27: 1557-1564.

23. Cantu RC, Li YM, Abdulhamid M, Chin LS. Return to play after cervical spine injuries in sports. Curr Sports Med Rep 2013; 12: 14-17.

24. Cantu RC. Dysautoregulation/Second-Impact Syndrome with Recurrent Athletic Head Injury. World Neurosurg 2016; 95: 601-602.

25. Carling C, Orhant E, LeGall F. Match injuries in professional soccer: inter-seasonal variation and effects of competition type, match congestion and positional role. Int J Sports Med 2010; 31: 271-276.

26. Casson IR, Viano DC, Powell JW, Pellmann EJ. Twelve Years of National Football League Concussion Data. Sports Health 2010; 2: 471-483.

27. Cavanaugh JT, Guskiewicz KM, Giuliani C, Marshall S, Mercer V, Stergiou N. Detecting altered postural control after cerebral concussion in athletes with normal postural stability. Br J Sports Med 2005; 39: 805-811.

28. Cazzaniga M, Ivry RB, Mangun GR (2014). Cognitive neuroscience: The biology of the mind (4th edition). W.W. Norton & Company, New York.

29. Chen JK, Johnston KM, Frey S, Petrides M, Worsley K, Ptito A. Functional abnormalities in symptomatic concussed athletes: an fMRI study. Neuroimage 2004; 22: 68-82.

30. Chen JK, Johnston KM, Collie A, McCrory P, Ptito A. A validation of the post-concussion symptom scale in the assessment of complex concussion using cognitive testing and functional MRI. J Neurol Neurosurg Psychiatry 2007; 78: 1231-1238.

31. Cole WR, Arrieux JP, Ivins BJ, Schwab KA, Qashu FM. A Comparison of Four Computerized Neurocognitive Assessment Tools to a Traditional Neuropsychological Test Battery in Service Members with and without Mild Traumatic Brain Injury. Arch Clin Neuropsychol 2018; 33: 102-119.

32. Covassin T, Elbin RJ, Stiller-Ostrowski JL, Kontos AP. Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) Practices of Sports Medicine Professionals. J Athl Train 2009; 44: 639-644.

33. Cross M, Kemp S, Smith A, Trewartha G, Stokes K. Professional Rugby Union players have a 60 % greater risk of time loss injury after concussion: a 2-season prospective study of clinical outcomes. Br J Sports Med 2016; 50: 926-931.

34. Dashnaw ML, Petraglia AL, Bailes JE. An overview of the basic science of concussion and subconcussion: where we are and where we are going. Neurosurg Focus 2012; 33: 1-9.

35. Davis GA, Purcell L, Schneider KJ, Yeates KO, Gioia GA, Anderson V, Ellenbogen RG, Echemendia RJ, Makdissi M, Sills A, Iverson GL, Dvořák J, McCrory P, Meeuwisse W, Patricios J, Giza CC, Kutcher JS. The Child Sport Concussion Assessment Tool 5th Edition (Child SCAT5): Background and rationale. Br J Sports Med 2017; 51: 859-861.

36. De Beaumont L, Théoret H, Mongeon D, Messier J, Leclerc S, Tremblay S, Ellemberg D, Lassonde M. Brain function decline in healthy retired athletes who sustained their last sports concussion in early adulthood. Brain 2009; 132: 695-708.

37. DeKosky ST, Ikonomovic MD, Gandy S. Traumatic brain injury – football, warfare, and long-term effects. N Engl J Med 2010; 363: 1293-1296.

38. Delaney J, Puni V, Rouah F. Mechanisms of injury for concussions in university football, ice hockey and soccer: a pilot study. Clin J Sport Med 2006; 16: 162-165.

39. Donaldson L, Asbridge M, Cusimano MD. Bodychecking rules and concussion in elite hockey. PLoS One 2013; 8: e69122.

40. Dunkley BT, Da Costa L, Bethune A, Jetly R, Pang EW, Taylor MJ, Doesburg SM. Low-frequency connectivity is associated with mild traumatic brain injury. Neuroimage Clin 2015; 7: 611-621.

41. Dusick JR, Wang C, Cohan P, Swerdloff R, Kelly DF. Pathophysiology of hypopituitarism in the setting of brain injury. Pituitary 2012; 15: 2-9.

42. Echemendia RJ, Meeuwisse W, McCrory P, Davis GA, Putukian M, Leddy J, Makdissi M, Sullivan SJ, Broglio SP, Raftery M, Schneider K, Kissick J, McCrea M, Dvořák J, Sills AK, Aubry M, Engebretsen L, Loosemore M, Fuller G, Kutcher J, Ellenbogen R, Guskiewicz K, Patricios J, Herring S. The Sport Concussion Assessment Tool 5th Edition (SCAT5): Background and rationale. Br J Sports Med 2017a; 51: 848-850.

43. Echemendia RJ, Meeuwisse W, McCrory P, Davis GA, Putukian M, Leddy J, Makdissi M, Sullivan SJ, Broglio SP, Raftery M, Schneider K, Kissick J, McCrea M, Dvořák J, Sills AK, Aubry M, Engebretsen L, Loosemore M, Fuller G, Kutcher J, Ellenbogen R, Guskiewicz K, Patricios J, Herring S. The Concussion Recognition Tool 5th Edition (CRT5): Background and rationale. Br J Sports Med 2017b; 51: 870-871.

44. Einaudi S, Bondone C. The effects of head trauma on hypothalamic function in children and adolescents. Curr Opin Pediatr 2007; 19: 465-570.

45. Eisenberg MA, Meehan WP 3rd, Mannix R. Duration and course of post-concussion symptoms. Pediatrics 2014; 133: 999-1006.

46. Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: the UEFA injury study. Br J Sports Med 2011; 45: 553-558.

47. 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: 732-737.

48. Falleti MG, Maruff P, Collie A, Darby DG. Practice effects associated with the repeated assessment of cognitive function using the CogState battery at 10-minute, one week and one month test-retest intervals. J Clin Exp Neuropsychol 2006; 28: 1095-1112.

49. Feddermann-Demont N, Straumann D, Dvořák J. Return to play management after concussion in football: recommendations for team physicians. J Sports Sci 2014; 32: 1217-1228.

50. FIFA. FIFA's Medical Committee proposes new protocol for the management of concussion. 2014. Retrieved on April 10th 2017 from http://www.fifa.com/development/news/y=2014/m=9/news=fifa-s-medical-committee-proposes-new-protocol-for-the-management-of-c-2443024.html

51. Finnoff JT, Jelsing EJ, Smith J. Biomarkers, genetics, and risk factors for concussion. PM R 2011; 3: S452-459.

52. Fino PC, Nussbaum MA, Brolinson PG. Locomotor deficits in recently concussed athletes and matched controls during single and dual-task turning gait: preliminary results. J Neuroeng Rehabil 2016; 13: 65-80.

53. Freeman WD, Aguilar MI. Intracranial hemorrhage: diagnosis and management. Neurol Clin 2012; 30: 211-240.

54. Freund HJ. Somatosensory and motor disturbances in patients with parietal lobe lesions. Adv Neurol 2003; 93: 179-193.

55. Fuller CW, Smith GL, Junge A, Dvorák J. The influence of tackle parameters on the propensity for injury in international football. Am J Sports Med 2004; 32: 43S-53S.

56. Fuller CW, Junge A, Dvorák 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: i3-i9.

57. Fuller CW, Ekstrand J, Junge A, Andersen TE, Bahr R, Dvorák 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: 193-201.

58. Gänsslen A, Schmehl I (2015). Leichtes Schädel-Hirn-Trauma im Sport. Handlungsempfehlungen [Craniocerebral injury. Recommendations]. Sportverlag Strauß, Bonn.

59. Galetta KM, Brandes LE, Maki K, Dziemianowicz MS, Laudano E, Allen M, Lawler K, Sennett B, Wiebe D, Devick S, Messner LV, Galetta SL, Balcer LJ. The King-Devick test and sports-related concussion: study of a rapid visual screening tool in a collegiate cohort. J Neurol Sci 2011; 309: 34-39.

60. Gao X, Chen J. Mild traumatic brain injury results in extensive neuronal degeneration in the cerebral cortex. J Neuropathol Exp Neurol 2011; 70: 183-191.

61. Gardner A, Kay-Lambkin F, Stanwell P, Donnelly J, Williams WH, Hiles A, Schofield P, Levi C, Jones DK. A systematic review of diffusion tensor imaging findings in sports-related concussion. J Neurotrauma 2012; 29: 2521-2538.

62. Gardner A, Iverson GL, McCrory P. Chronic traumatic encephalopathy in sport: a systematic review. Br J Sports Med 2014a; 48: 84-90.

63. Gardner A, Iverson GL, Stanwell P. A systematic review of proton magnetic resonance spectroscopy findings in sport-related concussion. J Neurotrauma 2014b; 31: 1-18.

64. Gaudet CE, Weyandt LL. Immediate Post-Concussion and Cognitive Testing (ImPACT): a systematic review of the prevalence and assessment of invalid performance. Clin Neuropsychol 2017; 31: 43-58.

65. Gavett BE, Stern RA, McKee AC. Chronic Traumatic Encephalopathy: A Potential Late Effect of Sport-Related Concussive and Subconcussive Head Trauma. Clin Sports Med 2011; 30: 179-188.

66. Gissane C, Jennings D, Kerr K, White J. Injury rates in rugby league football: impact of change in playing season. Am J Sports Med 2003; 31: 954-958.

67. Giza CC, Kutcher JS, Ashwal S, Barth J, Getchius TS, Gioia GA, Gronseth GS, Guskiewicz K, Mandel S, Manley G, McKeag DB, Thurman DJ, Zafonte R. Summary of evidence-based guideline update: evaluation and management of concussion in sports: report of the Guideline Development Subcommittee of the American Academy of Neurology. Neurology 2013; 80: 2250-2257.

68. Giza CC. Pediatric Issues in Sports Concussions. Continuum 2014a; 20: 1570-1587.

69. Giza CC, Hovda DA. The New Neurometabolic Cascade of Concussion. Neurosurgery 2014b; 75: S24-S33.

70. Goldenberg DC, Dini GM, Pereira MD, Gurgel A, Bastos EO, Nagarkar P, Gemperli R, Ferreira LM. Soccer-related Facial Trauma: Multicenter Experience in 2 Brazilian University Hospitals. Plast Reconstr Surg Glob Open 2014; 2: e168.

71. Gualtieri CT, Johnson LG. Reliability and validity of a computerized neurocognitive test battery, CNS Vital Signs. Arch Clin Neuropsychol 2006; 21: 623-643.

72. Guskiewicz KM, Mihalik JP. Biomechanics of Sport Concussion: Quest for the Elusive Injury Threshold. Exerc Sport Sci Rev 2011; 39: 4-11.

73. 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: 767-772.

74. Hägglund M, Waldén M, Ekstrand J. Injury recurrence is lower at the highest professional football level than at national and amateur levels: does sports medicine and sports physiotherapy deliver? Br J Sports Med 2016; 50: 751-758.

75. Hall RC, Hall RC, Chapman MJ. Definition, diagnosis, and forensic implications of postconcussional syndrome. Psychosomatics 2005; 46: 195-202.

76. Harmon KG, Drezner JA, Gammons M, Guskiewicz K, Halstead M, Herring S, Kutcher J, Pana A, Putukian M, Roberts W. American Medical Society for Sports Medicine position statement: concussion in sport. Br J Sports Med 2013; 47: 15-26.

77. Hart J Jr, Kraut MA, Womack KB, Strain J, Didehbani N, Bartz E, Conover H, Mansinghani S, Lu H, Cullum CM. Neuroimaging of cognitive dysfunction and depression in aging retired National Football League players: a cross-sectional study. JAMA 2013; 70: 326-335.

78. Hebert O, Schlueter K, Hornsby M, Van Gorder S, Snodgrass S, Cook C. The diagnostic credibility of second impact syndrome: A systematic literature review. J Sci Med Sport 2016; 19: 789-794.

79. Herman D, Zaremski JL, Vincent HK, Vincent KR. Effect of Neurocognition and Concussion on Musculoskeletal Injury Risk. Curr Sports Med Rep 2015; 14: 194-199.

80. Herman DC, Jones D, Harrison A, Moser M, Tillman S, Farmer K, Pass A, Clugston JR, Hernandez J, Chmielewski TL. Concussion May Increase the Risk of Subsequent Lower Extremity Musculoskeletal Injury in Collegiate Athletes. Sports Med 2017; 47: 1003-1010.

81. Hofman PA, Stapert SZ, van Kroonenburgh MJ, Jolles J, de Kruijk J, Wilmink JT. MR imaging, single-photon emission CT, and neurocognitive performance after mild traumatic brain injury. Am J Neuroradiol 2001; 22: 441-449.

82. Hohlrieder M, Hinterhoelzl J, Ulmer H, Lang C, Hackl W, Kampfl A, Benzer A, Schmutzhard E, Gassner R. Traumatic intracranial hemorrhages in facial fracture patients: review of 2,195 patients. Intensive Care Med 2003; 29: 1095-1100.

83. Hoogenboom BJ, Smith D. Management of bleeding and open wounds in athletes. Int J Sports Phys Ther 2012; 7: 350-355.

84. Huang MX, Nichols S, Baker DG, Robb A, Angeles A, Yurgil KA, Drake A, Levy M, Song T, McLay R, Theilmann RJ, Diwakar M, Risbrough VB, Ji Z, Huang CW, Chang DG, Harrington DL, Muzzatti L, Canive JM, Edgar C, Chen Y-H, Lee RR. Single-subject-based whole-brain MEG slow-wave imaging approach for detecting abnormality in patients with mild traumatic brain injury. Neuroimage Clin 2014; 5: 109-119.

85. Inglese M, Makani S, Johnson G, Cohen BA, Silver JA, Gonen O, Grossman RI. Diffuse axonal injury in mild traumatic brain injury: a diffusion tensor imaging study. J Neurosurg 2005; 103: 298-303.

86. Jantzen KJ, Anderson B, Steinberg FL, Kelso JA. A prospective functional MR imaging study of mild traumatic brain injury in college football players. Am J Neuroradiol 2004; 25: 738-745.

87. Johnson RS, Provenzano MK, Shumaker LM, Valovich-McLeod TC, Bacon CE. The Effect of Cognitive Rest as Part of Post-Concussion Management for Adolescent Athletes: A Critically Appraised Topic. J Sports Rehabil 2017; 26: 437-446.

88. Jordan BD. Chronic traumatic encephalopathy and other long-term sequelae. Continuum (Minneap Minn) 2014; 20: 1588-1604.

89. Junge A, Dvorák J. Injury surveillance in the World Football Tournaments 1998–2012. Br J Sports Med 2013; 47: 782-788.

90. Junge A, Dvorák J. Football injuries during the 2014 FIFA World Cup. Br J Sports Med 2015; 49: 599-602.

91. Karantzoulis S, Galvin JE. Distinguishing Alzheimer's disease from other major forms of dementia. Expert Rev Neurother 2011; 11: 1579-1591.

92. Keenan HT, Brundage SI, Thompson DC, Maier RV, Rivara FP. Does the face protect the brain? A case-control study of traumatic brain injury and facial fractures. Arch Surg 1999; 134: 14-17.

93. Khurana VG, Kaye AH. An overview of concussion in sport. J Clin Neurosci 2012; 19: 1-11.

94. Kim SY, Chan CL, Hyam DM. Facial fractures in football: incidence, site, and mechanism of injury. Br J Oral Maxillofac Surg 2016; 54: 936-940.

95. King NS. A systematic review of age and gender factors in prolonged post-concussion symptoms after mild head injury. Brain Inj 2014; 28: 1639-1645.

96. Kirkendall DT, Jordan SE, Garrett WE. Heading and head injuries in soccer. Sports Med 2001; 31: 369-386.

97. Knopman DS, Petersen RC. Mild cognitive impairment and mild dementia: a clinical perspective. Mayo Clin Proc 2014; 89: 1452-1459.

98. Kontos AP, Braithwaite R, Chrisman SP, McAllister-Deitrick J, Symington L, Reeves VL, Collins MW. Meta-analytical review of the effects of football heading. Br J Sports Med 2017; 51: 1118-1124.

99. Kristenson K, Bjørneboe J, Waldén M, Andersen TE, Ekstrand J, Hägglund M. The Nordic Football Injury Audit: higher injury rates for professional football clubs with third-generation artificial turf at their home venue. Br J Sports Med 2013; 47: 775-781.

100. Krutsch V, Gesslein M, Loose O, Weber J, Nerlich M, Gaensslen A, Bonkowsky V, Krutsch W. Injury mechanism of midfacial fractures in football causes in over 40% typical neurological smptoms of minor brain injuries. Knee Surg Sports Traumatol Arthrosc 2018; 26: 1295-1302.

101. Kuo C, Wu L, Loza J, Senif D, Anderson SC, Camarillo DB. Comparison of video-based and sensor-based head impact exposure. PLoS One 2018; 13: e0199238.

102. Kutcher JS, McCrory P, Davis G, Ptito A, Meeuwisse WH, Broglio SP. What evidence exists for new strategies or technologies in the diagnosis of sports concussion and assessment of recovery? Br J Sports Med 2013; 47: 299-303.

103. Leaper DJ. Traumatic and surgical wounds. BMJ 2006; 332: 532-535.

104. Lee RR, Huang M. Magnetoencephalography in the diagnosis of concussion. Prog Neurol Surg 2014; 28: 94-111.

105. Leventer L, Eek F, Hofstetter S, Lames M. Injury Patterns among Elite Football Players: A Media-based Analysis over 6 Seasons with Emphasis on Playing Position. Int J Sports Med 2016; 37: 898-908.

106. Levinson D, Reeves D, Watson J, Harrison M. Automated neuropsychological assessment metrics (ANAM) measures of cognitive effects of Alzheimer's disease. Arch Clin Neuropsychol 2005; 20: 403-408.

107. Levy ML, Kasabeh AS, Baird LC, amene C, Skeen J, Marshall L. Concussions in Soccer: A Current Understanding. World Neurosurg 2012; 78: 535-544.

108. Lewine JD, Davis JT, Bigler ED, Thoma R, Hill D, Funke M, Sloan JH, Hall S, Orrison WW. Objective documentation of traumatic brain injury subsequent to mild head trauma: multimodal brain imaging with MEG, SPECT, and MRI. J Head Trauma Rehabil 2007; 22: 141-155.

109. Li L, Sun G, Liu K, Li M, Li B, Qian SW, Yu LL. White Matter Changes in Posttraumatic Stress Disorder Following Mild Traumatic Brain Injury: A Prospective Longitudinal Diffusion Tensor Imaging Study. Chin Med J (Engl) 2016; 129: 1091-1099.

110. Ling H, Hardy J, Zetterberg H. Neurological consequences of traumatic brain injuries in sports. Mol Cell Neurosci 2015; 66: 114-122.

111. Liu H, Garrett WE, Moorman CT, Bing Y. Injury rate, mechanism, and risk factors of hamstring strain injuries in sports: A review of the literature. J Sport Health Sci 2012; 1: 92-101.

112. Lorberboym M, Lampl Y, Gerzon I, Sadeh M. Brain SPECT evaluation of amnestic ED patients after mild head trauma. Am J Emerg Med 2002; 20: 310-313.

113. Louey AG, Cromer JA, Schembri AJ, Darby DG, Maruff P, Makdissi M, Mccrory P. Detecting cognitive impairment after concussion: sensitivity of change from baseline and normative data methods using the CogSport/Axon cognitive test battery. Arch Clin Neuropsychol 2014; 29: 432-441.

114. Lynall RC, Mauntel TC, Padua DA, Mihalik JP. Acute Lower Extremity Injury Rates Increase after Concussion in College Athletes. Med Sci Sports Exerc 2015; 47: 2487-2492.

115. Maddocks DL, Dicker GD, Saling MM. The assessment of orientation following concussion in athletes. Clin J Sport Med 1995; 5: 32-35.

116. Maher ME, Hutchison M, Cusimano M, Comper P, Schweizer TA. Concussions and heading in soccer: a review of the evidence of incidence, mechanisms, biomarkers and neurocognitive outcomes. Brain Inj 2014; 28: 271-285.

117. Makdissi M, Darby D, Maruff P, Ugoni A, Brukner P, McCrory PR. Natural history of concussion in sport: markers of severity and implications for management. Am J Sports Med 2010; 38: 464-471.

118. Manley G, Gardner AJ, Schneider KJ, Guskiewicz KM, Bailes J, Cantu RC, Castellani RJ, Turner M, Jordan BD, Randolph C, Dvořák J, Hayden KA, Tator CH, McCrory P, Iverson GL. A systematic review of potential long-term effects of sport-related concussion. Br J Sports Med 2017; 51: 969-977.

119. Maroon JC, Winkelman R, Bost J, Amos A, Mathyssek C, Miele V. Chronic Traumatic Encephalopathy in Contact Sports: A Systematic Review of All Reported Pathological Cases. PLoS One 2015; 10: e0117338.

120. Martin RC 2nd, Spain DA, Richardson JD. Do facial fractures protect the brain or are they a marker for severe head injury? Am Surg 2002; 68: 477-481.

121. Martini DN, Sabin MJ, DePesa SA, Leal EW, Negrete TN, Sosnoff JJ, Broglio SP. The chronic effects of concussion on gait. Arch Phys Med Rehabil 2011; 92: 585-589.

122. Matser EJ, Kessels AG, Lezak MD, Jordan BD, Troost J. Neuropsychological impairment in amateur soccer players. JAMA 1999; 282: 971-973.

123. Mayer AR, Ling J, Mannell MV, Gasparovic C, Phillips JP, Doezema D, Reichard R, Yeo RA. A prospective diffusion tensor imaging study in mild traumatic brain injury. Neurology 2010; 74: 643-650.

124. McCarthy MT, Kosofsky BE. Clinical features and biomarkers of concussion and mild traumatic brain injury in pediatric patients. Ann N Y Acad Sci 2015; 1345: 89-98.

125. McCrea M, Kelly J, Randolph C, Kluge J, Bartolic E, Finn G, Baxter B. Standardised assessment of concussion (SAC): on site mental status evaluation of the athlete. J Head Trauma Rehab 1998; 13: 27-36.

126. McCrea M. Standardized mental status assessment of sports concussion. Clin J Sport Med 2001; 11: 176-181.

127. McCrea M, Iverson GL, Echemendia RJ, Makdissi M, Raftery M. Day of injury assessment of sport-related concussion. Br J Sports Med 2013a; 47: 272-284.

128. McCrea M, Guskiewicz K, Randolph C, Barr WB, Hammeke TA, Marshall SW, Powell MR, Woo Ahn K, Wang Y, Kelly JP. Incidence, clinical course, and predictors of prolonged recovery time following sport-related concussion in high school and college athletes. J Int Neuropsychol Soc 2013b; 19: 22-33.

129. McCrea M, Broshek DK, Barth JT. Sports concussion assessment and management: future research directions. Brain Inj 2015; 29: 276-282.

130. McCrory P, Davis G, Makdissi M. Second impact syndrome or cerebral swelling after sporting head injury. Curr Sports Med Rep 2012; 11: 21-23.

131. McCrory P, Meeuwisse WH, Kutcher JS, Jordan BD, Gardner A. What is the evidence for chronic concussion-related changes in retired athletes: behavioural, pathological and clinical outcomes? Br J Sports Med 2013; 47: 327-330.

132. McCrory P, Meeuwisse WH, Dvorák J, Aubry M, Bailes J, Broglio S, Cantu RC, Cassidy C, Echemendia RJ, Castellani RJ, Davis GA, Ellenbogen RG, Emery C, Engebretsen L, Feddermann-Demont N, Giza CC, Guskiewicz K, Herring S, Iverson GL, Johnston KM, Kissick J, Kutcher J, Leddy JL, Maddocks D, Makdissi M,Manley G, McCrea M, Meehan WP, Nagahiro S, Patricios J, Putukian M, Schneider KJ, Sills A, Tator CH, Turner M, Vos PE. Consensus statement on

concussion in sport- the 5th International Conference on Concussion in Sport held in Berlin, October 2016. Br J Sports Med 2017; 51: 838-847.

133. McKee AC, Stern RA, Nowinski CJ, Stein TD, Alvarez VE, Daneshvar DH, Lee HS, Wojtowicz SM, Hall G, Baugh CM, Riley DO, Kubilus CA, Cormier KA, Jacobs MA, Martin BR, Abraham CR, Ikezu T, Reichard, RR, Wolozin BL, Budson AE, Goldstein LE, Kowall NW, Cantu RC. The spectrum of disease in chronic traumatic encephalopathy. Brain 2013; 136: 43-64.

134. McKhann GM, Knopman DS, Chertkow H, Hyman BT, Jack jr CR, Kawas CH, Klunk WE, Koroshetz WJ, Manly JJ, Mayeux R, Mohs RC, Morris JC, Rossor MN, Scheltens P, Carrillo MC, Thies B, Weintraub S, Phelps CH. The diagnosis of dementia due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. Alzheimers Dement 2011; 7: 263-269.

135. Meehan 3rd WP, Mannis RC, O'Brien RJ, Collins MW. The Prevalence of Undiagnosed Concussions in Athletes. Clin J Sport Med 2013; 23: 339-342.

136. Meier TB, Brummel BJ, Singh R, Nerio CJ, Polanski DW, Bellgowan PS. The underreporting of self-reported symptoms following sports-related concussion. J Sci Med Sports 2015; 18: 507-511.

137. Moser RS, Glatts C, Schatz, P. Efficacy of immediate and delayed cognitive and physical rest for treatment of sports-related concussion. J Pediatr 2012; 161: 922-926.

138. Mucha A, Collins MW, Elbin RJ, Furman JM, Troutman-Enseki C, DeWolf RM, Marchetti G, Kontos AP. A Brief Vestibular/Ocular Motor Screening (VOMS) assessment to evaluate concussions: preliminary findings. Am J Sports Med 2014; 42: 2479-2486.

139. Murray N, Salvatore A, Powell D, Reed-Jones R. Reliability and validity evidence of multiple balance assessments in athletes with a concussion. J Athl Train 2014; 49: 540-549.

140. Netter FH (2015). Atlas der Anatomie [Atlas of Anatomy, 6th edition]. Urban & Fischer, München.

141. NFL's Head, Neck and Spine Committee. NFL Head, Neck and Spine Committee's Protocols Regarding Diagnosis and Management of Concussion. 2014. Retrieved on January 17th 2018 from http://www.nfl.com/news/story/0ap2000000254030/printable/head-neck-and-spine-committee-provides-protocol

142. Nicks BA, Ayello EA, Woo K, Nitzki-George D, Sibbald RG. Acute wound management: revisiting the approach to assessment, irrigation, and closure considerations. Int J Emerg Med 2010; 3: 399-407.

143. Niedfeldt MW. Head injuries, heading, and the use of headgear in soccer. Curr Sports Med Rep 2011; 10: 324-329.

144. Nilsson M, Hägglund M, Ekstrand J, Waldén M. Head and neck injuries in professional soccer. Clin J Sport Med 2013; 23: 255-260.

145. Noble JM, Hesdorffer DC. Sport-related concussions: a review of epidemiology, challenges in diagnosis, and potential risk factors. Neuropsychol Rev 2013; 23: 273-284.

146. Nordström A, Nordström P, Ekstrand J. Sports-related concussion increases the risk of subsequent injury by about 50% in elite male football players. Br J Sports Med 2014; 48: 1447-1450.

147. Ogawa K, Ishikawa H, Suzuki Y, Oishi M, Kamei S. Clinical study of the visual field defects caused by occipital lobe lesions. Cerebrovasc Dis 2014; 37: 102-108.

148. Okonkwo DO, Tempel ZJ, Maroon J. Sideline assessment tools for the evaluation of concussion in athletes: a review. Neurosurgery 2014; 75: 82-95.

149. Oldham JR, Munkasy BA, Evans KM, Wikstrom EA, Buckley TA. Altered dynamic postural control during gait termination following concussion. Gait Posture 2016; 49: 437-442.

150. Omalu BI, Bailes J, Hammers JL, Fitzsimmons RP. Chronic traumatic encephalopathy, suicides and parasuicides in professional American athletes: the role of the forensic pathologist. Am J Forensic Med Pathol 2010; 31: 130-132.

151. Pang EW, Dunkley BT, Doesburg SM, da Costa L, Taylor MJ. Reduced brain connectivity and mental flexibility in mild traumatic brain injury. Ann Clin Transl Neurol 2016; 3: 124-131.

152. Pappachan B, Alexander M. Correlating facial fractures and cranial injuries. J Oral Maxillofac Surg 2006; 64: 1023-1029.

153. Patricios J, Fuller GW, Ellenbogen R, Herring S, Kutcher JS, Loosemore M, Makdissi M, McCrea M, Putukian M, Schneider KJ. What are the critical elements of sideline screening that can be used to establish the diagnosis of concussion? A systematic review. Br J Sports Med 2017; 51: 888-894.

154. Perel P, Roberts I, Bouamra O, Woodford M, Mooney J, Lecky F. Intracranial bleeding in patients with traumatic brain injury: a prognostic study. BMC Emerg Med 2009; 9: 1-8.

155. Potts MB, Adwanikar H, Noble-Haeusslein LJ. Models of Traumatic Cerebellar Injury. Cerebellum 2009; 8: 211-221.

156. Prichep LS, McCrea M, Barr W, Powell M, Chabot RJ. Time course of clinical and electrophysiological recovery after sport-related concussion. J Head Trauma Rehabil 2013; 28: 266-273.

157. Prien A, Grafe A, Rössler R, Junge A, Verhagen E. Epidemiology of Head Injuries Focusing on Concussions in Team Contact Sports: A Systematic Review. Sports Med 2018; 48: 953-969.

158. Pulsipher DT, Campbell RA, Thoma R, King JH. A critical review of neuroimaging applications in sports concussion. Curr Sports Med Rep 2011; 10: 14-20.

159. Putukian M, Aubry M, McCrory P. Return to play after sports concussion in elite and non-elite athletes? Br J Sports Med 2009; 43: i28-31.

160. Reehal P. Facial injury in sport. Curr Sports Med Rep 2010; 9: 27-34.

161. Riley DO, Robbins CA, Cantu RC, Stern RA. Chronic traumatic encephalopathy: contributions from the Boston University Center for the Study of Traumatic Encephalopathy. Brain Inj 2015; 29: 154-163.

162. Rodrigues AC, Lasmar RP, Caramelli P. Effects of Soccer Heading on Brain Structure and Function. Front Neurol 2016; 7: 38.

163. Røe C, Sveen U, Alvsåker K, Bautz-Holter E. Post-concussion symptoms after mild traumatic brain injury: influence of demographic factors and injury severity in a 1-year cohort study. Disabil Rehabil 2009; 31: 1235-1243.

164. Romeo SJ, Hawley CJ, Romeo MW, Romeo JP. Facial Injuries in Sports: A Team Physician's Guide to Diagnosis and Treatment. Phys Sportsmed 2005; 33: 45-53.

165. Romeo SJ, Hawley CJ, Romeo MW, Romeo JP, Honsik KA. Sideline management of facial injuries. Curr Sports Med Rep 2007; 6: 155-161.

166. Ryan LM, Warden DL. Post-concussion syndrome. Int Rev Psychiatry 2003; 15: 310-316.

167. Sabini RC, Nutini DN, Nutini M. Return-to-play guidelines in concussion: revisiting the literature. Phys Sportsmed 2014; 42: 10-19.

168. Schneider KJ, Leddy JJ, Guskiewicz KM, Seifert T, McCrea M, Silverberg ND, Feddermann-Demont N, Iverson GL, Hayden A, Makdissi M. Rest and treatment/rehabilitation following sport-related concussion: a systematic review. Br J Sports Med 2017; 51: 930-934.

169. Schroeder GD, Vaccaro AR. Cervical spine injuries in the athlete. J Am Acad Orthop Surg 2016; 24: 122-133.

170. Shuttleworth-Edwards AB, Smith I, Radloff SE. Neurocognitive vulnerability amongst university rugby players versus noncontact sport controls. J Clin Exp Neuropsychol 2008; 30: 870-884.

171. Singh R, Meier TB, Kuplicki R, Svitz J, Mukai J, Cavanagh L, Allen T, Teague TK, Nerio C, Polasnki D, Bellgowan PS. Relationship of collegiate football experience and concussion with hippocampal volume and cognitive outcomes. JAMA 2014; 311: 1883-1888.

172. Slobounov SM, Zhang K, Pennell D, Ray W, Johnson B, Sebastianelli W. Functional abnormalities in normally appearing athletes following mild traumatic brain injury: a functional MRI study. Exp Brain Res 2010; 202: 341-354.

173. Sosnoff JJ, Broglio SP, Shin S, Ferrara MS. Previous mild traumatic brain injury and postural-control dynamics. J Athl Train 2011; 46: 85-91.

174. Spiotta AM, Bartsch AJ, Benzel EC. Heading in soccer: dangerous play? Neurosurgery 2012; 70: 1-11.

175. Stern RA, Riley DO, Daneshvar DH, Nowinski CJ, Cantu RC, McKee AC. Long-term consequences of repetitive brain trauma: chronic traumatic encephalopathy. PM R 2011; 3: 460-467.

176. Stubbe JH, van Beijsterveldt AM, van der Knaap S, Stege J, Verhagen EA, van Mechelen W, Backx FJ. Injuries in professional male soccer players in the Netherlands: a prospective cohort study. J Athl Train 2015; 50: 211-216.

177. Szczepanski SM, Knight RT. Insights into human behavior from lesions to the prefrontal cortex. Neuron 2014; 83: 1002-1018.

178. Talavage TM, Nauman EA, Breedlove EL, Yoruk U, Dye AE, Morigaki KE, Feuer H, Leverenz LJ. Functionally-detected cognitive impairment in high school football players without clinically-diagnosed concussion. J Neurotrauma 2014; 31: 327-338.

179. Teasdale G, Maas A, Lecky F, Manley G, Stocchetti N, Murray G. The Glasgow Coma Scale at 40 years: standing the test of time. Lancet Neurol 2014; 13: 844-854.

180. Thornton AE, Cox DN, Whitfield K, Fouladi R. Cumulative concussion exposure in rugby players: neurocognitive and symptomatic outcomes. J Clin Exp Neuropsychol 2008; 30: 398-409.

181. Tillmann BN (2016). Atlas der Anatomie des Menschen: mit Muskeltabellen [Atlas of Human Anatomy, 3rd edition]. Springer Verlag, Berlin Heidelberg.

182. Trepel M (2017). Neuroanatomie: Struktur und Funktion [Neuroanatomy: Structure and Function, 7th edition]. Urban & Fischer, München.

183. Tscholl P, O'Riordan D, Fuller CW, Dvorák J, Gutzwiller F, Junge A. Causation of injuries in female football players in top-level tournaments. Br J Sports Med 2007; 41: i8-i14.

184. van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. Sports Med 1992; 14: 82-99.

185. Vieira RC, Paiva WS, Vieira de Oliveira D, Teixeira MJ, Andrade AF, Sousa RC. Diffuse Axonal Injury: Epidemiology, Outcome and Associated Risk Factors. Front Neurol 2016; 7: 178.

186. Vincent AS, Roebuck-Spencer T, Gilliland K, Schlegel R. Automated Neuropsychological Assessment Metrics (v4) Traumatic Brain Injury Battery: military normative data. Mil Med 2012; 177: 256-269.

187. 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: 542-546.

188. Waldén M, Krosshaug T, Bjørneboe J, Andersen TE, Faul O, Hägglund M. Three distinct mechanisms predominate in non-contact anterior cruciate ligament injuries in male professional football players: a systematic video analysis of 39 cases. Br J Sports Med 2015; 49: 1452-1460.

189. Williams WH, Potter S, Ryland H. Mild traumatic brain injury and Postconcussion Syndrome: a neuropsychological perspective. J Neurol Neurosurg Psychiatry 2010; 81: 1116-1122.

190. Williamson IJS, Goodman D. Converging evidence for the under-reporting of concussions in youth ice hockey. Br J Sports Med 2006; 40: 128-132.

191. Withnall C, Shewchenko N, Gittens R, Dvorák J. Biomechanical investigation of head impacts in football. Br J Sports Med 2005; 39: 49-57.

192. Xu J, Rasmussen IA, Lagopoulos J, Haberg A. Diffuse axonal injury in severe traumatic brain injury visualized using high-resolution diffusion tensor imaging. J Neurotrauma 2007; 24: 753-765.

193. Zuckerman SL, Kerr ZY, Yengo-Kahn A, Wassermann E, Covassin T, Solomon GS. Epidemiology of Sports-Related Concussion in NCAA Athletes From 2009-2010 to 2013-2014: Incidence, Recurrence, and Mechanisms. Am J Sports Med 2015; 43: 2654-2662.

Curriculum Vitae

Appendix

The appendix includes the original manuscripts in the following order:

1. Time trends of head injuries over multiple seasons in professional male football (soccer).
2. Match situations leading to head injuries in professional male football (soccer) – a video-based analysis over 12 years.
3. Head injuries in professional male soccer over 13 years – 29% lower incidence rates after of a rule change (red card).

Note. This article will be published in a forthcoming issue of the Journal *'Sports Medicine International Open'*. The article appears here in its accepted and peer-reviewed form. It has not been copyedited, proofread, or formatted by the publisher.

Section: Original research

Journal: Sports Medicine International Open

Article title: Time trends of head injuries over multiple seasons in professional male football (soccer)

Authors: Florian Beaudouin [1], Karen aus der Fünten [1], Tobias Tröss [1], Claus Reinsberger [2], Tim Meyer [1]

Affiliations: 1 Institute of Sports and Preventive Medicine, Saarland University, Saarbrücken, Germany. 2 Institute of Sports Medicine, University of Paderborn, Paderborn, Germany.

Acceptance Date: November 13th 2018

Original research

Time trends of head injuries over multiple seasons in professional male football (soccer)

Florian Beaudouin [1*], Karen aus der Fünten [1], Tobias Tröss [1], Claus Reinsberger [2], Tim Meyer [1]

1 Institute of Sports and Preventive Medicine, Saarland University, Saarbrücken, Germany

2 Institute of Sports Medicine, University of Paderborn, Paderborn, Germany

***Corresponding author**: Florian Beaudouin

Institute of Sports and Preventive Medicine, Saarland University, Campus, Building B 8-2, 66123 Saarbrücken, Germany

Telephone number: +49 681-302 70400

Fax: + 49 681-302 4296

E-mail: florian.beaudouin@uni-saarland.de

Funding: This study was funded by the German Federal Institute of Sports Science (BISp).

Conflict of Interest: None.

Acknowledgment: The authors wish to thank the “kicker Sportmagazin” magazine for granting access to their online editions and the German Federal Institute of Sports Science (BISp) for their funding.

Original research

Time trends of head injuries over multiple seasons in professional male football (soccer)

Abstract

The present study aimed to investigate time trends of head injuries and their injury mechanisms since a rule change as monitoring may help to identify causes of head injuries and may advance head injury prevention efforts.

Based on continuously recorded data from the German football magazine “kicker Sportmagazin®” as well as other media sources, a database of head injuries in the 1st German male Bundesliga was generated comprising 11 seasons (2006/07-2016/17). Injury mechanisms were analysed from video recordings. Injury incidence rates (IR) and 95% confidence intervals (95% CI) were calculated. Time trends were analysed via linear regression.

238 match head injuries occurred (IR 1.77/1000 match hours, 95% CI 1.56-2.01). There were no significant seasonal changes, expressed as annual average year on year change, in IRs over the 11-year period for total head injuries (p=0.693), facial/head fractures (p=0.455), lacerations/abrasions (p=0.162), and head contusions (p=0.106). The annual average year on year increase for concussion was 6.4% (p=0.004). Five head injury mechanisms were identified. There were no seasonal changes in injury mechanisms over the study period.

The subcategory concussion increased slightly over the seasons which may either be a result of increasing match dynamics or raised awareness among team physicians and players.

Key words: concussion; sport injury; epidemiology

Introduction

Prospective studies on head and neck injuries in professional male football (soccer) identified the unfair use of the upper extremity (particularly the elbow) as a significant cause of head and neck injuries.[1, 15] As a consequence, the International Football Association Board (IFAB) changed the rules of the game in 2006 and deemed deliberate blows to the head from the elbow an instant red card offence. The effect of this rule change has previously been investigated by comparing head injury data of the seasons 2000/01-20005/06 with data of the seasons 2007/08-2012/13.[3] Consequently, this preventative measure appeared to be efficient in reducing the number of head injuries (29% lower incidence rates after this rule change). When considering the reported rise in the speed, technique, equipment, game play in general (e.g. tactics), increased number of matches in the seasonal schedule, time pressure, and general pressure on players, [2, 7, 37] appropriate head injury monitoring is desirable. This approach may help to identify mechanisms and causes of head injuries and lead to advances in injury prevention strategies.

Currently, limited information is available on time trends of head injury rates over multiple seasons in professional male football.[11, 33] This study intends to add beneficial information on the incidence of these injuries over a longitudinal period since the aforementioned IFAB rule change. This analysis includes the seasons after the rule change, but adds more seasons to expand the head injury database. Therefore, the present study (i) investigates the long-term seasonal variation of head injuries (and their diagnoses) sustained during match-play after the rule change in the 2006/07 season for 11 consecutive seasons and (ii) investigates the long-term seasonal variation of the most common mechanisms leading to head injuries in elite male football players. We hypothesized that head injuries and their mechanisms would present a continuous unaltered time trend over the years.

Methods

Study design and injury assessment

A standardized analysis of match head injuries in the first male German Bundesliga was completed encompassing the seasons 2006/07 to 2016/17 (11 full seasons; seasons 2006/07 to 2013/14 retrospectively and seasons 2014/15 to 2016/17 prospectively). Since the 2006/07 season, intentional elbow to head blows have been punished with a red card. Data collection followed an a priori protocol and analysis plan. Data were mainly identified by a structured search in the sports magazine "kicker Sportmagazin®" (online edition). The magazine offers publicly available clinical information (diagnosis and time loss) and is published twice weekly with one journalist being responsible for one club and having contact with the press office of the club every day. The magazine contains injury reports and summaries of each match. The online versions also offered the opportunity for a free text search. Search terms were: concussions; traumatic brain injury; contusion; fracture, laceration; abrasion; face; head; neck; skull; cranium; zygomatic bone; mandible; maxilla; nose; eye. Additionally, web pages (transfermarkt.de, ligainsider.de), social media of the players and teams (Twitter, Facebook and Instagram), team homepages and newsletters, TV sports channels (e.g. Sky Sports News), and local news (e.g. newspapers) were screened as a secondary data source to gain additional information on injuries by using the aforementioned search terms as well. Training head injuries are considerably lower compared to match head injuries and were not considered.[33] The injury mechanisms were assessed by video recordings. No research ethics board approval[21] was required for this study as all data were collected from public sources.[10]

Data on diagnoses such as concussions/traumatic brain injuries (TBI), facial/head contusions, facial/head fractures, and facial/head lacerations/abrasions were collected. Injuries with an unclear description and unknown diagnosis were categorized as "other head injury". In case an injury encompassed more than one diagnosis, the most severe injury was recorded. For injuries with an unknown outcome (e.g., towards the end of the season), the mean time loss for the particular diagnosis in the present database was considered. The severity of injuries was based on the time loss according to the consensus statement in previous football injury research,[16] which are categorised as slight (time loss 0 days); minimal (1-3 days); mild (4-7 days); moderate (8-28 days); and severe (>28 days).

Incident assessment

Categories for the head impact events during matches were:[3]

- Injury causation: contact with opponent or team mate, no contact with player, or unknown
- Injury mechanisms: head contact with head, hand, arm (forearm and upper arm), elbow, shoulder, pelvis, trunk, foot, knee, lower leg, thigh, ball, ground, advertising boards/goalpost/corner flag

These criteria are in accordance with the analyses of injury mechanisms that have previously been published.[15, 34, 36] Video recordings were obtained from the official German Football League ("Die Liga – Fußballverband (DFL)") and wyscout®. Wyscout is a video platform (payment required) that offers full matches of all European leagues. Additionally, different video sequences (actions, players etc.) are readily available on the platform. Head injuries without video recordings are included in the analyses referring to total numbers and percentages.

Match exposure

Match exposure per team was calculated using the following calculation:[16] number of games x number of players on the field (11 players) x duration of the game in hours (1.5 hours per match). The analysis included the 34 games in the regular Bundesliga season as well as additional cup games (e.g. DFB-Pokal and the UEFA Champions-League). Extra time in knock out games (2 x 15 minutes) was also included. Preparation and friendly games as well as national games were not analysed in this study.

Statistical analysis

All statistical analyses were performed using Microsoft Excel 2010 and Statistica 8 (Statsoft Europe GmbH, Hamburg, Germany). Injury incidence rates (IR) were calculated with the following formula:[16] Incidence = (number of injuries / hours of match exposure) × 1000. For the incidence rates, 95% confidence intervals (CI) were calculated as follows:[18]

Lower 95% CI = Incidence / $e^{1.96 \times \text{(square root [1/number of incidents])}}$

Upper 95% CI = Incidence * $e^{1.96 \text{ x (square root [1/number of incidents])}}$

Time trends, expressed as the average annual percentages of change, were analysed using a linear regression model with the log-transformed IR as the dependent variable.[12, 19] The significance level was set at $p<0.05$.

Results

Exposure, time loss and injury incidence rates

Total match exposure was 134,541 hours. 238 head injuries occurred corresponding to an IR of 1.77 (95% CI 1.56-2.01) per 1000 match hours. The IR for body contact-related head injuries was 1.50 (95% CI 1.31-1.72) per 1000 match hours. The head injury IRs per season across the 11-year study period are shown in table 1.

The average time loss for total head injuries was 8 ± 10 days (median 4, range 0-80 days). Average time loss for concussion was 10 ± 10 days (median 6, range 1-47 days), for facial/head contusions 5 ± 5 days (median 3, range 1-21 days), for facial/head fractures 13 ± 16 days (median 7, range 1-80 days), and for facial/head lacerations/abrasions 4 ± 4 days (median 4, range 0-32 days). The time loss per season is displayed in table 1. The proportion of head injuries with an unknown outcome was 3%. Of the 238 head injuries, 215 (90%) could be analysed via video. The remaining 23 (10%) could not be analysed in detail as either the video recordings were unavailable (5%, n=12) or, despite the video recordings being present, the injury mechanism was not apparent (5%, n=11).

Head injury epidemiology and time trends

Time trends for all head injury types as well as the 2-year moving average (MA) are shown in figure 1. No seasonal changes were found in the IRs for total head injuries (R^2=0.018, b=0.010, 95% CI -0.046 to 0.066, p=0.693), facial/head fractures (R^2=0.064, b=0.047, 95% CI -0.089 to 0.184, p=0.455), facial/head lacerations/abrasions (R^2=0.205, b=-0.048 95% CI -0.119 to 0.023, p=0.162), or facial/head contusions (R^2=0.263, b=0.107, 95% CI -0.028 to 0.242, p=0.106). The annual average year on year increase for concussion was 6.4% (R^2=0.623, b=0.064, 95% CI 0.026 to 0.101, p=0.004).

Head injury mechanisms and time trends

The five predominant head injury mechanisms were head against head contacts (38%, IR 0.67/1000 match hours, 95% CI 0.54-0.82), elbow to head blows (16%, IR 0.29/1000 match hours, 95% CI 0.21-0.40), foot to head contacts (9%, IR 0.16/1000 match hours, 95% CI 0.11-0.25), hand to head (5%, IR

0.09/1000 match hours, 95% CI 0.05-0.16), and knee to head contacts (5%, IR 0.09/1000 match hours, 95% CI 0.05-0.16).

The time trends for the five most frequent head injury mechanisms are shown in figure 2. Head-head (R^2=0.056, b=0.028, 95% CI -0.058 to 0.113, p=0.483), elbow-head (R^2=0.002, b=-0.003, 95% CI -0.046 to 0.041, p=0.894), foot-head (R^2=0.009, b=-0.004, 95% CI -0.036 to 0.028, p=0.0781), hand-head (R^2=0.058, b=0.005, 95% CI -0.010 to 0.021, p=0.474), and knee-head (R^2=0.024, b=-0.004, 95% CI -0.022 to 0.014, p=0.652) remained stable over 11 consecutive seasons.

Discussion

The main finding of this present study is that there were no significant seasonal changes for the IRs of total head injuries as well as for most of the subcategories such as facial/head fractures, facial/head lacerations/abrasions, and facial/head contusions over the 11-year period among male professional football players. The main head injury mechanisms also showed no sign of change across the time period. However, an exception was the IR of concussion as it increased significantly year on year by 6.4%.

The IRs of head injuries in this study were lower (approximately up to 20 times) compared to high-risk sports such as American football, ice hockey or rugby,[8-10, 17, 39] but still noteworthy as they can potentially to lead to long-term sequelae such as postconcussion syndrome (PCS) or – if they occur repetitively - chronic neurocognitive impairment (CNI), or even chronic traumatic encephalopathy (CTE).[20, 27, 29] Although the present IRs ranged between 1.1 and 3.1 per 1000 match hours, it is likely that the true number of head injuries is somewhat higher due to the potential underreporting of injuries, as their signs and symptoms can rapidly change as well as rapidly disappear.[29] Head traumas/concussions are considered to be one of the most complex acute injuries in sports medicine to diagnose, assess and manage.[29] To date there is no perfect diagnostic test or marker for the immediate diagnosis of concussions.[29] The true number of unreported concussions in professional football is still unknown, but it appears that up to 30% of all concussions remain undiagnosed throughout different sports.[30, 31, 38] Undiagnosed concussions may be the result of being overlooked by non-medical professionals and/or even medical staff due to mild symptoms or even because of trivialized post-injury signs by the players themselves.

Compared to other football studies, the present IRs appear to be slightly higher. Head injury incidence rates of 0.74 – 1.70 per 1000 match hours have been reported in the last years,[1, 6, 33] whilst other studies found lower IRs as a result of adding training exposures to their analyses.[11, 36] Injury rates in training are considerably low compared to match rates.[12] Nilsson et al. reported a 38-fold higher rate of head injuries during matches compared with training and even 78-fold higher rate of concussions in matches.[33] The highest number of head injuries were reported during FIFA World

Cup tournaments. Fuller et al. reported an incidence rate of head injuries of 12.5 per 1000 match hours with regards to 20 FIFA international tournaments.[15] Other tournament-related head injury data showed an almost similar incidence rate of 11.3 and 9.3 per 1000 match hours.[23, 24] It seems evident that it is difficult to compare head injury data from international tournaments with head injury data from regular league activity.

In the precursor study, the comparison of head injuries that were sustained before the rule change in the 2006/07 season and data afterwards revealed a decrease of 29%.[3] The total IRs for the 11 season period remained lower compared to the seasons 2000/01-2005/06. Nevertheless, ongoing head injury monitoring remains essential in order to continue identifying the risk of sustaining head injuries and potential sequelae. Monitoring head injuries offers the opportunity to prevent their increase. Most head injury types showed no significant seasonal changes over 11 consecutive seasons, whereas the rate of concussions increased significantly by 6.4%. This development is surprising. Potentially, the increasing awareness of head injuries in professional football over the last years may be a reasonable/valid explanation and responsible for the increase as more concussions may be reported.[20, 27, 29] Additionally, increasing match dynamics over the years could contribute to increasing numbers of concussions. Speed, techniques, equipment and game play in general (e.g. tactics) seem to experience a continuously evolution.[7, 37] Especially physical and technical demands have increased substantially.[2] It is feasible and comprehensible that these evolutional trends may transfer to different (head) injuries as well.

Time loss and, consequently, breaks from football can differ regarding specific head injury types, but can also be dependent on appropriate treatment, recovery and injury complications. More comprehensive injuries (more than one diagnosis) might prolong the anticipated recovery time and thus the time loss and the return to play. The mean time loss for concussions was 10 days in this study, which is in accordance with a previous study in which the mean time loss was 10.5 days.[33] Return to play after sustaining a concussion was previously recommended after 7–10 days.[29] However, symptoms may persist even longer (e.g. PCS).[20, 25, 28] The median time loss was 6 days suggesting that some concussed players returned to play in less than 1 week despite current consensus recommendations that emphasise a sufficient rest period to achieve full recovery.[29]

Head to head contact was the main injury mechanism for head injuries in this study. It accounted for 38% of all head injuries and remained stable throughout the 11 season time period. It has previously been considered to be the predominant injury mechanism with regard to the causation of head injuries.[14, 33] Similarly, the elbow to head mechanism did not change either over this time period. The rule change in 2006 was able to reduce elbow to head blows by about 23% when compared to seasons before the rule change.[3] A reduced number of elbow to head contacts was also described by Bjørneboe et al. after stricter interpretation of the rules over the duration of one season, supporting this decrease.[6]

Prevention strategies and methods are required as head injuries bear the risk of long-term and potentially life-threatening consequences.[22] As most head injuries are the result of head to head contact, prohibiting intentional elbow blows to the head may have only had a limited effect on the number of head injuries (which is possibly already "harvested" by the rule change). Instead, diminishing head to head contacts could be the target of future prevention strategies. Although, it is impossible to reduce or even eliminate any contact between players. A logical step in the light of head injury prevention from a solely medical point of view the final solution would be banning these football-specific features that cause head to head contacts (e.g. header duels) from the game. But undoubtedly, this would change the "heart of football" as this is a fundamental part of football. Understanding potentially modifiable risk factors (e.g. fatigue, prior concussion, excessive post-injury exercise) would help to design, implement and evaluate appropriate prevention interventions to reduce the risk of head injuries.[13, 29] Protective equipment such as head gear was previously discussed as a potential prevention tool, but currently there is no clear evidence of reduced frequencies or severity of head injuries in football.[20, 27, 32] Potentially, specific strength training for the head-neck segment could be a reasonable method to reduce head injuries or at least their severity. Strong neck muscles may limit transmitted forces to the head and may stabilize the head during head impacts.[4, 20]

However, the personal awareness of an imminent impact seems to be crucial as otherwise the player may be unable to adequately prepare the head-neck muscles for the upcoming impact forces.[20, 33]

Methodological considerations and limitations

Mixing retrospective data with prospective data inherits a large risk for bias as the prospective data are most likely recorded more precisely/complete and are therefore more accurate. However, as a prospective approach was not feasible for the seasons 2006/07 to 2013/14 (and given the fact that strength of data collection in professional male football is the accuracy of time loss recording as full-time football players are seen daily by the medical staff and the fact that news including injuries are reported extensively by various media), the present analyses appear to be fairly complete. Furthermore, prospective data collection may increase head injury numbers as a result of increased registries, but this development was not apparent. Additionally, since the start of social media, the information about injuries and personal data of players has increased tremendously over the years and despite this increased availability of information and increased interest in detailed players' data, the overall head injury incidence rate has not raised. Nevertheless, it remains possible that the increase in concussions may have been triggered by the prospective data collection in some seasons. Additionally, there may be some bias as injury reports by media sources have unarguably increased since 2006. The present database does not include training head injuries as these injuries are considerably lower compared to match head injuries. The present data were not validated with medical records by each team's medical departments. The medical data were published by non-medical professionals and club staff and, thus, their accuracy should be interpreted with caution. Despite this unknown validity in our database, this limitation most likely has no influence on our main hypothesis "time trends", because this limitation may be consistent over the years. Diagnoses obtained from medical records are the gold standard for research purposes,[1, 6, 15, 33] but online sports databases have been previously used to gather information on injuries in professional football.[26] But even for gold standard research there is no guarantee of data integrity. Bjørnboe et al. found that medical staff reports underestimated the incidence of time-loss injuries by up to 20%.[5]

Head injury mechanisms were investigated via video recordings. Ideally, the video recordings should provide various perspectives, slow motions and display high solution quality. These prerequisites were not always met, e.g. younger injuries compared to older injuries during the study period.

To evaluate time trends in head injury characteristics, we used a linear regression with log-transformed IRs as the dependent variable. This methodological approach was also conducted by Ekstrand et al. who analysed time-trends in injury characteristics over 11 consecutive seasons with regard to muscle and ligament injuries in football.[12] However, time trends of facial/head lacerations/abrasions as well as the head injury mechanisms elbow-head, foot-head, hand-head, and knee-head had to be calculated with their IR without log-transformation as they contained the value "zero". To date, it seems that no gold standard exists to evaluate time-trends in injury characteristics over multiple seasons.[12]

Conclusion

The number, type and injury mechanisms of match head injuries among male professional football players remained stable with no seasonal variation over 11 consecutive seasons of the German Bundesliga since the rule change that penalized elbow blows to the head in 2006. However, the subcategory concussion increased slightly year on year over the seasons which may either be a result of increasing match dynamics or raised awareness among team physicians. No seasonal trends were seen in head injury mechanisms. Further preventative strategies are required to decrease head injuries in professional male football. For instance, protective equipment could become promising. Furthermore, equally important as diminishing the number of head injuries is improving the accuracy in diagnosing and managing concussions. New protocols similar to NFL's "concussion safety protocol" could help to raise further awareness and recognition of concussions.

References

1. Andersen TE, Arnason A, Engebretsen L, Bahr R. Mechanisms of head injuries in elite football. Br J Sports Med 2004; 38: 690-696
2. Barnes C, Archer DT, Hogg B, Bush M, Bradley PS. The Evolution of physical and technical performance parameters in the English Premier League. Int J Sports Med 2014; 35: 1095-1100
3. Beaudouin F, aus der Fünten K, Tröß T, Reinsberger C, Meyer T. Head injuries in professional male football (soccer) over 13 years – 29% lower incidence rates after of a rule change (red card). Br J Sports Med 2017 Jun 23. [Epub ahead of print]
4. Becker S, Fröhlich M, Kelm J, Ludwig O. Change of Muscle Activity as Well as Kinematic and Kinetic Parameters during Headers after Core Muscle Fatigue. Sports 2017; 5: 1-7
5. Bjørneboe J, Flørenes TW, Bahr R, Andersen TE. Injury surveillance in male professional football; is medical staff reporting complete and accurate? Scand J Med Sci Sports 2011; 21: 713-720
6. Bjørneboe J, Bahr R, Dvorak J, Andersen TE. Lower incidence of arm-to-head contact incidents with stricter interpretation of the laws of the game in Norwegian male professional football. Br J Sports Med 2013; 47: 508-514
7. Bush M, Barnes C, Archer DT, Hogg B, Bradley PS. Evolution of match performance parameters for various playing positions in the English Premier League. Hum Mov Sci 2015; 39: 1-11
8. Casson IR, Viano DC, Powell JW, Pellman EJ. Twelve Years of National Football League Concussion Data. Sports Health 2010; 2: 471-483
9. Cross M, Kemp S, Smith A, Trewartha G, Stokes K. Professional Rugby Union players have a 60 % greater risk of time loss injury after concussion: a 2-season prospective study of clinical outcomes. Br J Sports Med 2016; 50: 926-931
10. Donaldson L, Asbridge M, Cusimano MD. Bodychecking rules and concussion in elite hockey. PLoS One 2013; 8: e69122
11. Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: the UEFA injury study. Br J Sports Med 2011; 45: 553-558

12. 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: 732-737
13. Finnoff JT, Jelsing EJ, Smith J. Biomarkers, genetics, and risk factors for concussion. PM R 2011; 3: S452-459
14. 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: 43S-53S
15. 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: i3-i9
16. 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: 193-201
17. Gissane C, Jennings D, Kerr K, White J. Injury rates in rugby league football: impact of change in playing season. Am J Sports Med 2003; 31: 954-958
18. Hägglund M, Walden 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: 767-772
19. Hägglund M, Walden M, Ekstrand J. Injury recurrence is lower at the highest professional football level than at national and amateur levels: does sports medicine and sports physiotherapy deliver? Br J Sports Med 2016; 50: 751-758
20. 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: 15-26
21. Harriss DJ, Macsween A, Atkinson G. Standards for Ethics in Sport and Exercise Science Research: 2018 Update. Int J Sports Med 2017; 38: 1126-1131
22. Jordan BD. Chronic traumatic encephalopathy and other long-term sequelae. Continuum (Minneap Minn) 2014; 20: 1588-1604

23. Junge A, Dvorak J. Injury surveillance in the World Football Tournaments 1998–2012. Br J Sports Med 2013; 47: 782-788
24. Junge A, Dvorak J. Football injuries during the 2014 FIFA World Cup. Br J Sports Med 2015; 49: 599-602
25. King NS. A systematic review of age and gender factors in prolonged post-concussion symptoms after mild head injury. Brain Inj 2014; 28: 1639-1645
26. Leventer L, Eek F, Hofstetter S, Lames M. Injury Patterns among Elite Football Players: A Media-based Analysis over 6 Seasons with Emphasis on Playing Position. Int J Sports Med 2016; 37: 898-908
27. Levy ML, Kasabeh AS, Baird LC, Amene C, Skeen J, Marshall L. Concussions in Soccer: A Current Understanding. World Neurosurg 2012; 78: 535-544
28. McCrea M, Guskiewicz K, Randolph C, Barr WB, Hammeke TA, Marshall SW, Powell MR, Woo Ahn K, Wang Y, Kelly JP. Incidence, clinical course, and predictors of prolonged recovery time following sport-related concussion in high school and college athletes. J Int Neuropsychol Soc 2013; 19: 22-33
29. McCrory P, Meeuwisse WH, Dvorak J, Aubry M, Bailes J, Broglio S, Cantu RC, Cassidy D, Echemendia RJ, Castellani RJ, Davis GA, Ellenbogen R, Emery C, Engebretsen L, Feddermann-Demont N, Giza CC, Guskiewicz KM, Herring S, Iverson GL, Johnston KM, Kissick J, Kutcher J, Leddy JJ, Maddocks D, Makdissi M, Manley GT, McCrea M, Meehan WP, Nagahiro S, Patricios J, Putukian M, Schneider KJ, Sills A, Tator CH, Turner M, Vos PE. Consensus statement on concussion in sport - the 5th International Conference on Concussion in Sport held in Berlin, October 2016. Br J Sports Med 2017; 51: 838-847
30. Meehan 3rd WP, Mannis RC, O'Brien RJ, Collins MW. The Prevalence of Undiagnosed Concussions in Athletes. Clin J Sport Med 2013; 23: 339-342
31. Meier TB, Brummel BJ, Singh R, Nerio CJ, Polanski DW, Bellgowan PS. The underreporting of self-reported symptoms following sports-related concussion. J Sci Med Sports 2015; 18: 507-511

32. Niedfeldt MW. Head injuries, heading and the use of headgear in soccer. Curr Sports Med Rep 2011; 10: 324-329

33. Nilsson M, Hägglund M, Ekstrand J, Waldén M. Head and neck injuries in professional soccer. Clin J Sport Med 2013; 23: 255-260

34. 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: i15-i19

35. 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: i8-i14

36. 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: 542-546

37. Wallace JL, Norton KI. Evolution of World Cup soccer final games 1966-2010: game structure, speed and play patterns. J Sci Med Sport 2014; 17: 223-228

38. Williamson IJS, Goodman D. Converging evidence for the under-reporting of concussions in youth ice hockey. Br J Sports Med 2006; 40: 128-132

39. Zuckerman SL, Kerr ZY, Yengo-Kahn A, Wassermann E, Covassin T, Solomon GS. Epidemiology of Sports-Related Concussion in NCAA Athletes From 2009-2010 to 2013-2014: Incidence, Recurrence, and Mechanisms. Am J Sports Med 2015; 43: 2654-2662

Table 1 Head injury incidence rates and time loss from the season 2006/2007 to 2016/2017

Seasons	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	Total Seasons
Total head injuries	1.81 [1.19-2.75]	1.44 [0.91-2.28]	1.13 [0.67-1.90]	1.80 [1.18-2.73]	1.74 [1.14-2.67]	3.05 [2.21-4.20]	2.11 [1.44-3.10]	1.58 []1.00-2.47]	1.48 [0.93-2.35]	1.55 [0.99-2.42]	1.81 [1.19-2.75]	1.77 [1.56-2.01]
Concussions/TBIs	0.41 [0.17-0.99]	0.48 [0.22-1.07]	0.32 [0.12-0.86]	0.41 [0.17-0.98]	0.58 [0.28-1.22]	0.49 [0.22-1.10]	0.57 [0.27-1.19]	0.58 [0.28-1.22]	0.49 [0.22-1.10]	0.81 [0.44-1.51]	0.74 [0.39-1.42]	0.53 [0.42-0.67]
Facial/head fractures	0.08 [0.01-0.59]	0.56 [0.27-1.17]	0.32 [0.12-0.86]	0.65 [0.33-1.31]	0.33 [0.13-0.88]	0.66 [0.33-1.32]	0.73 [0.38-1.40]	0.41 [0.17-1.00]	0.25 [0.08-0.77]	0.33 [0.12-0.87]	0.41 [0.17-0.99]	0.43 [0.33-0.56]
Lacerations / abrasions	0.74 [0.39-1.42]	0.32 [0.12-0.85]	0.24 [0.08-0.75]	0.57 [0.27-1.27]	0.42 [0.17-1.00]	1.24 [0.74-2.05]	0.49 [0.22-1.08]	0.25 [0.08-0.77]	0.33 [0.12-0.88]	0	0	0.42 [0.33-0.55]
Head contusions	0.33 [0.12-0.88]	0.08 [0.01-0.57]	0.16 [0.04-0.64]	0.08 [0.01-0.58]	0.42 [0.17-1.00]	0.49 [0.22-1.10]	0.16 [0.04-0.65]	0.25 [0.08-0.77]	0.25 [0.08-0.77]	0.33 [0.12-0.87]	0.66 [0.33-1.32]	0.30 [0.22-0.41]
Other head injuries	0.25 [0.08-0.77]	0	0.08 [0.01-0.57]	0.08 [0.01-0.58]	0	0.17 [0.04-0.66]	0.16 [0.04-0.65]	0.08 [0.01-0.59]	0.08 [0.01-0.59]	0.08 [0.01-0.58]	0	0.09 [0.05-0.16]
Mean ± SD time loss (days)	5±5	17±16	12±10	8±6	6±5	8±9	7±8	4±3	8±16	10±18	5±5	8±10
Median time loss (days)	4	14	9	6	5	5	5	3	2	4	3	4
Range time loss (days)	0-18	3-54	2-32	2-26	2-22	1-28	2-38	1-14	1-70	1-80	1-15	0-80
0 days (slight)	4	0	0	0	0	0	0	0	0	0	0	4
1-3 days (minimal)	5	2	2	6	6	8	7	12	10	7	11	76
4-7 days (mild)	7	6	4	8	13	19	14	5	3	6	6	91
8-28 days (moderate)	6	5	7	8	2	8	3	2	4	5	5	55
>28 days (severe)	0	5	1	0	0	2	2	0	1	1	0	12

Numbers are incidence rates (IR = number of injuries per 1000 match hours) with the 95% confidence intervals in parentheses; SD: standard deviation; TBI: traumatic brain injury.

Fig. 1 Seasonal variation in head injury rates in 11 consecutive seasons. * p <0.05.

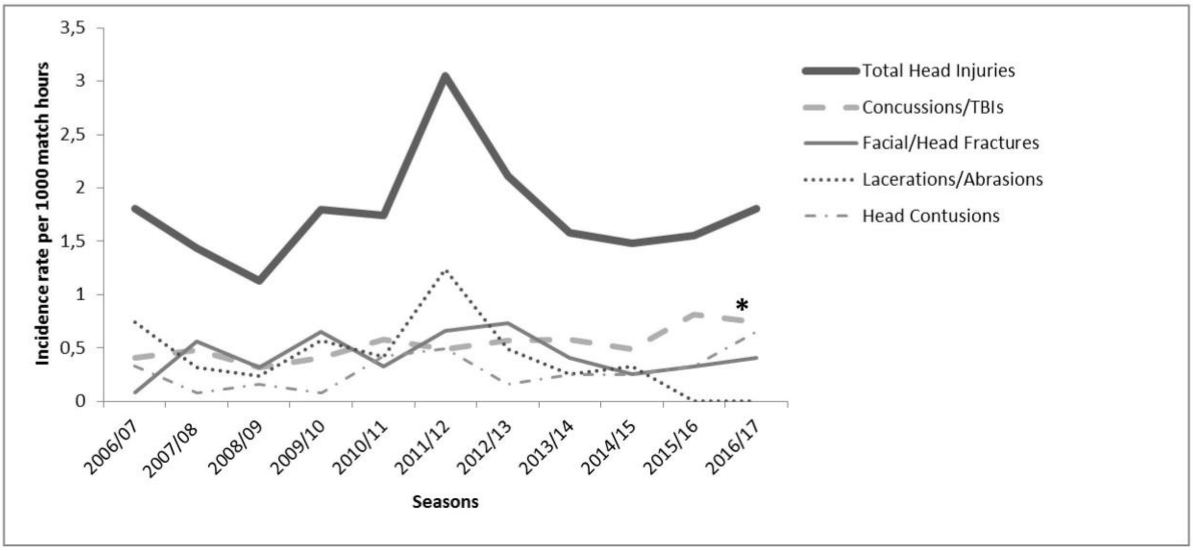
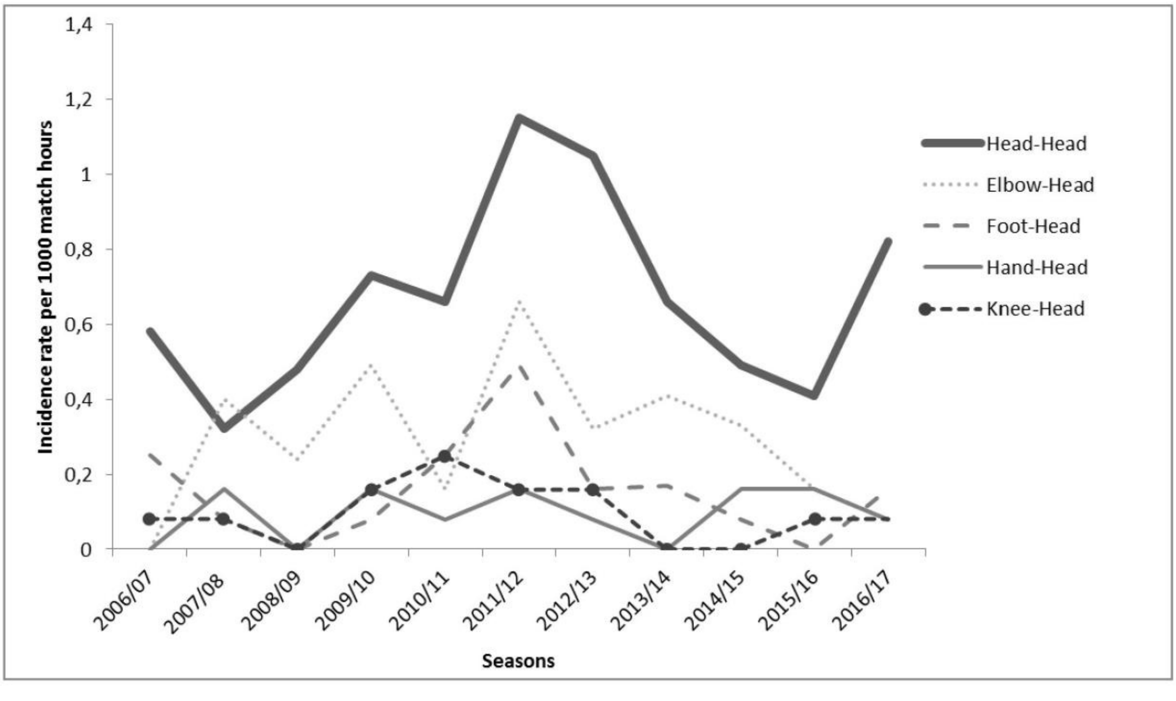


Fig. 2 Seasonal variation in head injury mechanisms in 11 consecutive seasons.



Match Situations Leading to Head Injuries in Professional Male Football (Soccer)—A Video-based Analysis Over 12 Years

Florian Beaudouin, MSc,* Karen aus der Fünten, MD,* Tobias Tröß, BA,* Claus Reinsberger, MD, PhD,† and Tim Meyer, MD, PhD*

Abstract

Objective: To identify risk situations promoting head injuries in professional male football (soccer) and to investigate the impact of a rule change in 2006 punishing elbow-head contacts. **Design:** Analysis of video sequences of head events leading to head injury. **Participants:** Professional football players of the first male German Bundesliga. **Main Outcome Measures:** Observational criteria of head impacts on video recordings (players' actions preceding head injuries, foul play—referee's decision and assessment of rater, ball possession, on-pitch medical treatment, and consequences of head impact). **Results:** Three hundred thirty-four head injuries were reported in kicker Sportmagazin corresponding to an incidence rate of 2.25 (95% confidence interval 2.01-2.51) per 1000 player match hours. The injured player predominantly jumped (60%), headed the ball (36%), or ran forwards (20%); the noninjured players mainly jumped (64%), headed the ball (27%), or raised the elbow to the head (23%). Free ball situations (2 players challenge for the ball) caused most of the head injuries (81%). The players' action "raising the elbow" during a head injury seemed to be lower after the rule change. **Conclusions:** Jumping for the ball with the intention of heading is the predominant action associated with head injury risk. Head injuries occur most often when players challenge for the ball in a header duel. As head injuries bear the potential risk of long-term health sequelae, the identification of situational circumstances is essential to develop preventative means in the future.

Key Words: soccer, head impact, head trauma, injury situations, risk reduction

(*Clin J Sport Med* 2018;00:1–6)

INTRODUCTION

The frequency of head injuries in professional football (soccer) is rather low compared with other contact or collision sports such as American football, rugby, or ice hockey.[1–6] Head traumas in football typically occur because of body or object contact such as goal posts, balls, or the ground.[5,6] Head traumas such as sport-related concussions may cause long-lasting impairment.[7–9] Potentially, repetitive head traumas may be a risk factor for an impairment of long-term brain health.[10,11]

To prevent head injuries, it is necessary to know typical circumstances of such incidents: the players' actions on the pitch immediately preceding the head injury, and the ball possession status seem to be important aspects in this regard.[12,13] For this purpose, video analysis is a useful technique.[5,6,12,14–18] Fuller et al[6,19] investigated injury mechanisms leading to head and neck injuries in international tournaments through this technique. They identified clash of heads and furthermore elbow to head strikes as the main cause of head injuries. As a consequence, the International Football Association Board (IFAB) enforced a rule change in 2006: Intentional elbow to head strikes had subsequently to be penalized with a red card. The influence of this rule change on head injuries has not yet been investigated.

The primary purpose of this study was to describe and assess circumstances immediately preceding head injuries in professional male football. A secondary aim was to investigate whether the rule change affected these circumstances. The analysis of various head injury types and their distinct injury mechanism are published elsewhere.[20]

METHODS

Study Sample and Design

A retrospective analysis of head injuries in the first male German Bundesliga was completed encompassing the seasons 2000/2001 to 2012/2013. There are 18 teams in the league with a mean of 570 active players in total per season. The rule change (red card in case of intentional elbow to head strikes) was introduced at the beginning of the season 2006/2007, which was excluded from statistical analysis to guarantee an even distribution of seasons before and after the rule change and to allow for accustomization of players and referees to the

Submitted for publication May 18, 2017; accepted December 14, 2017.

*From the *Institute of Sports and Preventive Medicine, Saarland University, FIFA—Medical Centre of Excellence, Saarbrücken, Germany; and †Institute of Sports Medicine, University of Paderborn, Paderborn, Germany.*

Supported by the German Federal Institute of Sports Science (BiSp).

The authors report no conflicts of interest.

Corresponding Author: Florian Beaudouin, MSc, Institute of Sports and Preventive Medicine, Saarland University, Campus, Bldg B 8-2, 66123 Saarbrücken, Germany (florian.beaudouin@uni-saarland.de).

http://dx.doi.org/10.1097/JSM.0000000000000572

new rule. This season was thus seen as a transition season. No Research Ethics Board approval was required for this study because all data were collected from public sources.[21]

Data Collection

At first, head injuries were identified by a structured search in the German football magazine "kicker Sportmagazin," which is published twice weekly with 1 journalist being responsible for 1 club and having contact with the club every day. The magazine presents injury reports. In addition, a free-text search with defined search terms was conducted. It provided all relevant data on diagnosis such as concussions/traumatic brain injuries, contusions, facial fractures, and lacerations/abrasions. The diagnoses were forwarded by team officials. Afterward, video sequences of these head injuries were obtained from the official German Football League ["Die Liga—Fußballverband (DFL)"]. Circumstances leading to head impacts and subsequently head injuries were analyzed from those video recordings.[6,12,21]

Incident Assessment

The observational criteria of head impacts during matches are listed below.[6,12,18,19] In case, a head injury involved a player–player contact, the second player is referred to as the "noninjured player." A "free ball" situation means 2 players challenge for the ball at the same time. "Player's ball possession" implies that 1 player is clearly in possession of the ball. Head injuries without video recordings are excluded in the analyses referring to total numbers and percentages.

- Action performed by the noninjured player: heads the ball, 1/2 footed tackle, slides in, raises elbow, pushes injured player, runs into injured player, runs (forwards, backwards, and sideways), falls on the injured player, jumps (sideways, forwards, backwards, and upwards), and stands.
- Action performed by the injured player: heads the ball, 1/2 footed tackle, slides in, raises elbow, pushes opponent, runs into opponent/team mate, runs (forwards, backwards, and sideways), runs against goal/corner flag/advertising boards, falls on the noninjured player, falls on the ground, jumps (sideways, forwards, backwards, and upwards), and stands.
- Foul—referee decision: yes, no card, yellow card, red card, and no.
- Foul—assessment of rater (football-experienced sports scientist): yes, no card, yellow card, red card, and no.
- Injured player aware of imminent impact: yes, no.
- Ball possession status at the time of the incident: injured player in ball possession, noninjured player in ball possession, and free ball.
- Bleeding as consequences of the head impact: yes, no.
- On-pitch treatment—first aid: yes, no.

Match Exposure

Match exposure was recorded using the following calculation[22]: number of games × number of players on the field × duration of the game in hours (1.5 hours per match). This analysis included 34 games per team in the regular season plus games in official national and international competitions, for example, UEFA Champions-League or national DFB-Cup (DFB-Pokal). Extra time in knock out games (2 × 15 minutes) was also enclosed.

Statistics

All statistical analyses were performed with Windows Excel 2010. The incidence rate (IR) for total head injuries was calculated with the following formula: incidence = (number of injuries/hours of match exposure) × 1000. For the IRs, 95% confidence intervals (CIs) were calculated[23]:

$$\text{Lower 95\% CI} = \text{Incidence}/e1.96 \times (\text{square root } [1/\text{number of incidents}]).$$

$$\text{Upper 95\% CI} = \text{Incidence} \times e1.96 \times (\text{square root } [1/\text{number of incidents}]).$$

Chi-square analyses were performed to determine differences between the 2 periods. Descriptive data are presented as absolute numbers with percentages in parentheses. The significance level was set at $P < 0.05$.

RESULTS

This study includes 334 head injuries (196 head injuries during 2000/2001-2005/2006 and 138 during 2007/2008-2012/2013) corresponding to an IR of 2.25 (95% CI, 2.02-2.51) per 1000 player match hours. Of these 334 head injuries, 21% (n = 69) could not be analyzed in detail as either the video recordings were unavailable (17.5%, n = 58) or, despite the video recordings being present, the injury mechanism was not apparent (3.5%, n = 11). For the first period (2000/2001-2005/2006), 48 head injuries (25%) could not be analyzed and for the second period (2007/2008-2012/2013), 21 (15%).

Exposure

The total football exposure for all 12 seasons was 148 269 player match hours and 74 519.5 player match hours for the seasons 2000/2001 to 2005/2006 and 73 749.5 for 2007/2008 to 2012/2013.

Players' Actions

Tables 1 and 2 display the results of the video analysis. The 3 most frequent actions performed by the noninjured players at the time of the injury were jumping (sideways, backwards, forwards, and upwards) (64%), heading the ball (27%), or raising the elbow to the head (23%). The injured player predominantly jumped (sideways, backwards, forwards, and upwards) (60%), headed the ball (36%), or ran forwards (20%). No head injury of this study occurred after solely heading the ball in the light of purposeful heading with no contact with an opponent. Between seasons 2000/2001 to 2005/2006 and 2007/2008 to 2012/2013, the action "raising the elbow to head" was reduced by 23%. However, there was no large difference for either the injured or the noninjured player, if the 3 most frequent actions were compared. Seventy one percent of the injured players were aware of the imminent contact with either a player or an object.

Foul Play—Referee's Decision and Assessment of Rater

The referee rated 74% of the head injuries as no foul play. The foul assessment of the rater (football-experienced sports

TABLE 1. Video Analysis of Head Injuries (n = 334)—Actions of the Players

Seasons	2000/2001-2005/2006	2007/2008-2012/2013	χ^2 and *P*
Action of the noninjured player			
Jumps in total	86 (58)	84 (72)	5.32, **0.021**
Jumps sideways	4 (3)	4 (3)	0.12, 0.74
Jumps forwards	31 (21)	36 (31)	3.34, 0.07
Jumps backwards	9 (6)	2 (1)	3.14, 0.08
Jumps upwards	42 (28)	42 (36)	1.71, 0.19
Heads the ball	34 (23)	38 (33)	2.98, 0.84
Raises elbow to head	35 (24)	27 (23)	0.01, 0.91
Runs forwards	26 (18)	20 (17)	0.01, 0.92
Runs into injured player	15 (10)	12 (10)	0.01, 0.97
Runs backwards	0	1	—
Stands	9 (6)	17 (15)	5.27, 0.22
1/2 footed tackle	6 (4)	16 (14)	7.95, **0.005**
Slides in	2 (1)	6 (5)	3.18, 0.07
Pushes injured player	3 (2)	1	0.60, 0.44
Falls on the injured player	3 (2)	1	0.60, 0.44
Unknown	48 (25)	21 (15.5)	4.25, **0.039**
Action of the injured player			
Jumps in total	79 (53)	79 (68)	5.43, 0.20
Jumps sideways	4 (3)	4 (3)	0.12, 0.74
Jumps forwards	26 (18)	30 (26)	2.56, 0.11
Jumps backwards	0	1	—
Jumps upwards	49 (33)	44 (38)	0.82, 0.37
Heads the ball	43 (29)	51 (44)	6.03, **0.014**
Runs forward	23 (16)	29 (25)	3.54, 0.06
Runs into opponent/team mate/object	15 (10)	8 (7)	0.90, 0.34
Runs backwards	1	1	0.03, 0.86
Stands	10 (7)	13 (11)	1.56, 0.21
1/2 footed tackle	14 (10)	6 (5)	1.76, 0.19
Slides in	10 (7)	9 (8)	1.09, 0.77
Falls to the ground	8 (5)	1	4.13, **0.042**
Raises elbow	0	0	—
Pushes opponent	0	0	—
Runs against goal/corner flag/bank	0	0	—
Falls on the noninjured player	0	0	—
Unknown	48 (25)	21 (15.5)	4.25, **0.039**

% in parentheses; values < 1% are not mentioned; χ^2 = chi-square test; 196 head injuries were sustained during seasons 2000/2001 to 2005/2006 and 138 during 2007/2008 to 2012/2013. Significance level $p < 0.05$.

scientist) resulted in 62% in a no foul decision. The referee rated 26% of the head injuries as foul play and the rater 38%. In 7%, the referee showed the yellow card, the rater would have performed it in 24%.

Ball Possession, On-Pitch Medical Treatment, and Consequences of Head Impact

Eighty-one percent of the head injuries occurred during a free ball situation. On-pitch treatment was applied in 88%, 12% were untreated. Bleeding occurred in 54% of the head injuries.

DISCUSSION

Many studies in professional football have used video recordings to analyze injury mechanisms and their risk factors.[12,14–18] However, only few research groups investigated head injuries specifically and these studies were conducted more than a decade ago.[5,6,19] Considering the rapidly changing nature of football concerning speed, techniques, equipment, and game play in general (eg, tactics),[24] a re-evaluation of factors promoting head injuries is important. Most players who suffered from a head injury were aware of the imminent contact with either an object or another player. This aspect is essential, as

TABLE 2. Video Analysis of Head Injuries (n = 334)—Further Observations

Seasons	2000/2001-2005/2006	2007/2008-2012/2013	χ^2 and *P*
Foul referee decision			
Yes	36 (25)	34 (27)	0.13, 0.71
No card	25 (17)	19 (15)	0.26, 0.61
Yellow card	7 (5)	13 (10)	2.90, 0.88
Red card	1	2 (2)	0.49, 0.49
No	109 (75)	93 (73)	0.13, 0.71
Unknown	51 (26)	11 (8)	17.45, **<0.00001**
Foul—assessment of rater			
Yes	51 (38)	51 (39)	0.06, 0.81
No card	12 (9)	20 (15)	2.63, 0.11
Yellow card	36 (27)	28 (21)	0.95, 0.33
Red card	2 (1)	1	0.30, 0.58
No	85 (62)	80 (61)	0.06, 0.81
Unknown	60 (31)	7 (5)	32.94, **<0.00001**
Injured player aware of imminent impact			
Yes	101 (83)	86 (66)	0.14, 0.71
No	48 (17)	45 (34)	0.14, 0.71
Unknown	47 (24)	7 (5)	21.36, **<0.00001**
Ball possession status at the time of the injury			
Injured player	10 (7)	8 (6)	0.07, 0.79
Noninjured player	23 (16)	11 (8)	3.56, 0.06
Free ball	113 (77)	113 (86)	3.07, 0.08
Unknown	50 (25)	6 (4)	25.99, **<0.00001**
Consequences of the head impact—bleeding			
Yes	85 (57)	67 (50)	1.41, 0.24
No	63 (43)	66 (50)	1.41, 0.24
Unknown	48 (25)	5 (3)	26.41, **<0.00001**
On-pitch treatment			
Yes	130 (88)	119 (88)	0.01, 0.94
No	17 (12)	16 (12)	0.01, 0.94
Unknown	49 (25)	3 (2)	32.10, **<0.00001**

% in parentheses; values <1% are not mentioned; χ^2 = chi-square test; rater (football-experienced sport scientist); 196 head injuries were sustained during seasons 2000/2001 to 2005/2006 and 138 during 2007/2008 to 2012/2013.
Significance level $p < 0.05$.

it allows the anticipation of the impact and subsequently offers the opportunity to react accordingly, to reduce the force of the impact and thus the severity of head injuries.

Players' Action

In this study, jumping for the ball was the most frequently performed action by the injured as well as by the noninjured players at the time of the head injury. This is in line with Fuller et al's findings.[6] Especially free ball situations, when 2 players challenge for the ball in the air, had a greater propensity for injury in this study. The main aim of jumping is heading the ball. However, the ball as such does not seem to be a main risk factor for head traumas in professional football. Only 26% of the head injuries involved contact with the ball. No head injury of this study occurred after solely heading the ball, supporting this finding. This is also in accordance with the results of Fuller et al.[6] They reported a low IR of 0.05/1000 football hours for head injuries because of solely heading the ball. Therefore, heading as such seems to be a rather low-risk activity in the light of traumatic head injuries. However, these results do not allow conclusions about the risk of gradual onset or chronic head injuries. Body contact either with the opponent or sometimes with the team mate is the main risk factor for head injuries. Previously published studies reported that especially elbow to head mechanisms were responsible. They caused up to 35% of all head injuries.[2,5,6] As a consequence, the IFAB introduced a new rule in 2006 punishing conscious elbow to head movements with a red card. In the current study, a raised elbow to head by the noninjured player accounted for 23% of all head injuries. The number seemed to be lower by 23% after the rule change. It remains unknown how much the missing video recordings would have changed the players' action elbow–head contact.

Ball Possession and Foul Decision

The ball possession of the injured player has previously been discussed as risk factor having the greatest impact on the incidence of head injuries in football.[6]

Most injuries occurred after a free ball. Three-fourths of the duels were assessed as fair play and compliant with the current laws of the game by the referee. Most head to head contacts occurred therefore accidentally. Only 31% of all head injuries that occurred because of elbow to head contacts were assessed as foul plays. This emphasizes that in most duels an intentional strike with a part of the upper extremity, for example, the elbow, has not been the predominant action used by the noninjured player. Nevertheless, the raters assessed foul plays more frequently than the referees and decided to punish foul plays more often with a yellow card. But, no difference was found for red card decisions. Furthermore, there were no more red cards after the rule change in 2006. Low red card decisions were also found in a recent study with stricter interpretation of the rules over 1 season.[25] It seems that it is rather difficult for referees to recognize foul plays appropriately.[25]

The remaining foul plays involved contact with a lower extremity, for example, a raised leg/foot. A rule penalizing "dangerous play" already exists. Nevertheless, punishing elbow strikes was a logical step following on from Fuller et al's[6] and Andersen et al's[5] results whose numbers were considerably higher compared with the results in this study. Reasons for this development may be the rule change in the first place. Less foul plays, an increase in fair play "thoughts" during header duels or an improved players' athletic performance allowing for higher jumps without the momentum's support by using the upper extremities might also explain this change.

Aware of Imminent Contact

Most players were most likely aware of an imminent impact. Being aware of the imminent contact is essential because it allows for the anticipation of the situation. The latter can reduce the injury risk as the player could, for example, activate his neck muscles to reduce head acceleration or he could try to move his head out of reach.[26] Low head–neck muscle mass with reduced muscle strength was previously discussed as being a risk factor for high head accelerations in football with a subsequent high risk of head injuries.[27] Thus, specific strength training for shoulder and neck musculature, teaching heading skills, improving peripheral vision, and reaction time may be recommended to prevent head injuries, although more data are needed to confirm and quantify efficacy. In addition, improving core and leg strength may help to maintain a stable position in the air during headers.

Methodological Considerations

The head injuries were identified by a structured search in the football magazine "kicker Sportmagazin," which is published twice weekly with 1 journalist being responsible for 1 club. This man power and expertise should allow for a decent accuracy of data.

The retrospective approach through an online open-source sports database has been previously used to gather information on injuries in professional football.[28] Ideally, the video recordings should provide various perspectives, slow motions, and display a good quality. These prerequisites were not always met, for example, some injuries could be evaluated by 1 perspective only. Furthermore, 21% of the head injuries were not available on video recordings (eg, international games were completely missing or the injury was not caught on camera). The evaluation of on-pitch treatment, bleedings and referees' foul decisions require longer video sequences. Some sequences were stopped immediately after the head injury occurred making the assessment of those criteria impossible. Incidence rates and IR ratios were not calculated for the observational categories, as the large missing numbers of video sequences would have underestimated these rates. Unfortunately, the present data may be confounded by the relative number of missing data values. In addition, missing data were different between the 2 periods impairing the comparisons of observational criteria. Nevertheless, in this analysis, 21% of the head injuries were not completely available on video recordings. This percentage is in accordance with a previous study in which 20% were not identified.[18] Other video analysis–based studies could not identify about 34%[6] and 35%.[5]

As this analysis was based on retrospective data, the assessment of variables (eg, team habits, playing tactics, etc.), that may have contributed to injury risk, was not feasible. Furthermore, potential confounding factors such as age, height, weight, experience, player's position, or previous injury could not be obtained.

CONCLUSIONS

The present data suggest that jumping with the intention of heading the ball is the predominant players' action leading to a head injury. The rule change in 2006 led potentially to a reduction of "raising the elbow to head" movements that were deemed responsible for head injuries in many cases. Free balls caused by far the most head injuries as compared to being in ball possession. Using high-quality video material in future may help to keep identifying head injury prone match situations to develop preventative means.

ACKNOWLEDGMENTS

The authors thank the "kicker Sportmagazin" magazine for granting access to their online issues. The video recordings were obtained from the official German Football League ["Die Liga—Fußballverband (DFL)"].

References

1. Nilsson M, Hägglund M, Ekstrand J, et al. Head and neck injuries in professional soccer. *Clin J Sport Med*. 2013;23:255–260.
2. Delaney JS, Al-Kashmiri A, Correa JA. Mechanisms of injury for concussions in university football, ice hockey, and soccer. *Clin J Sport Med*. 2014;24:233–237.
3. Noble JM, Hesdorffler DC. Sport-related concussions: a review of epidemiology, challenges in diagnosis, and potential risk factors. *Neuropsychol Rev*. 2013;23:273–284.
4. Zuckerman SL, Kerr ZY, Yengo-Kahn A, et al. Epidemiology of sports-related concussions in national collegiate athletic association athletes from 2009-2010 to 2013-2014: incidence, recurrence, and mechanisms. *Am J Sports Med*. 2015;43:2654–2662.
5. Andersen TE, Arnason A, Engebretsen L, et al. Mechanisms of head injuries in elite football. *Br J Sports Med*. 2004;38:690–696.
6. 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:i3–i9.

7. Harmon KG, Drezner JA, Gammons M, et al. American Medical Society for Sports Medicine position statement: concussion in sport. *Br J Sports Med*. 2013;47:15–26.
8. Khurana VH, Kaye AH. An overview of concussion in sport. *J Clin Neurosci*. 2012;19:1–11.
9. Stern RA, Riley DO, Daneshvar DH, et al. Long-term consequences of repetitive brain trauma: chronic traumatic encephalopathy. *PM R*. 2011; 3:S460–S467.
10. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med*. 2017;51:838–847.
11. Manley GT, Gardner AJ, Schneider KJ, et al. A systematic review of potential long-term effects of sport-related concussion. *Br J Sports Med*. 2017;51:969–977.
12. Tscholl P, O'Riordan D, Fuller CW, et al. Tackle mechanisms and match characteristics in women's elite football tournaments. *Br J Sports Med*. 2007;41:i15–i19.
13. Rahnama N, Reilly T, Lees A. Injury risk associated with playing actions during competitive soccer. *Br J Sports Med*. 2002;36:354–359.
14. 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;30:165–170.
15. Hawkins RD, Fuller CW. An examination of the frequency and severity of injuries and incidents at three levels of professional football. *Br J Sports Med*. 1998;32:326–332.
16. Andersen TE, Tenga A, Engebretsen L, et al. Video analyses of injuries and incidents in Norwegian professional football. *Br J Sports Med*. 2004;38: 626–631.
17. Arnasen A, Tenga A, Engebretsen L, et al. A prospective video-based analysis of injury situations in elite male football. *Am J Sports Med*. 2004; 32:1459–1465.
18. Tscholl P, O'Riordan D, Fuller CW, et al. Causation of injuries in female football players in top-level tournaments. *Br J Sports Med*. 2007;41:i8–i14.
19. Fuller CW, Smith GL, Junge A, et al. The influence of tackle parameters on the propensity for injury in international football. *Am J Sports Med*. 2004; 32:43S–53S.
20. Beaudouin F, aus der Fünten K, Tröß T, et al. Head injuries in professional male football (soccer) over 13 years—29% lower incidence rates after a rule change (red card). *Br J Sports Med*. 2017. doi: 10.1136/bjsports-2016-097217. [epub ahead of print].
21. Donaldson L, Asbridge M, Cusimano MD. Bodychecking rules and concussion in elite hockey. *PLoS One* 2013;8:e69122.
22. Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Br J Sports Med*. 2006;40:193–201.
23. Hägglund M, Walden 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;40:767–772.
24. Barnes C, Archer DT, Hogg B, et al. The Evolution of physical and technical performance parameters in the English Premier League. *Int J Sports Med*. 2015;39:1–11.
25. Bjørneboe J, Bahr R, Dvorak J, et al. Lower incidence of arm-to-head contact incidents with stricter interpretation of the laws of the game in Norwegian male professional football. *Br J Sports Med*. 2013;47: 508–514.
26. Hrysomallis C. Neck muscular strength, training, performance and sport injury risk: a review. *Sports Med*. 2016;46:1111–1124.
27. Caccesse JB, Kaminski TW. Minimizing head acceleration in soccer: a review of the literature. *Sports Med*. 2016;46:1591–1604.
28. Leventer L, Eek F, Hofstetter S, et al. Injury patterns among elite football players: a media-based analysis over 6 seasons with emphasis on playing position. *Int J Sports Med*. 2016;37:898–908.

BJSM Online First, published on July 1, 2017 as 10.1136/bjsports-2016-097217

Head injuries in professional male football (soccer) over 13 years: 29% lower incidence rates after a rule change (red card)

Florian Beaudouin,[1] Karen aus der Fünten,[1] Tobias Tröß,[1] Claus Reinsberger,[2] Tim Meyer[1]

[1]Institute of Sports and Preventive Medicine, Saarland University, FIFA - Medical Centre of Excellence, Saarbrücken, Germany
[2]Institute of Sports Medicine, University of Paderborn, Paderborn, Germany

Correspondence to
Florian Beaudouin, Institute of Sports and Preventive Medicine, Saarland University, Campus, Building B 8-2, 66123 Saarbrücken, Germany; florian.beaudouin@uni-saarland.de

Received 3 November 2016
Revised 3 May 2017
Accepted 15 May 2017

To cite: Beaudouin F, aus der Fünten K, Tröß T, *et al*. *Br J Sports Med* Published Online First: [*please include* Day Month Year]. doi:10.1136/bjsports-2016-097217

ABSTRACT

Background Absolute numbers of head injuries in football (soccer) are considerable because of its high popularity and the large number of players. In 2006 a rule was changed to reduce head injuries. Players were given a red card (sent off) for intentional elbow-head contact.

Aims To describe the head injury mechanism and examine the effect of the rule change.

Methods Based on continuously recorded data from the German football magazine "kicker", a database of all head injuries in the 1st German Male Bundesliga was generated comprising seasons 2000/01-2012/13. Injury mechanisms were analysed from video recordings. Injury incidence rates (IR) and 95% confidence intervals (95% CI) as well as incidence rate ratios (IRR) to assess differences before and after the rule change were calculated.

Results 356 head injuries were recorded (IR 2.22, 95% CI 2.00 to 2.46 per 1000 match hours). Contact with another player caused most head injuries, more specifically because of head-head (34%) or elbow-head (17%) contacts. After the rule change, head injuries were reduced by 29% (IRR 0.71, 95% CI 0.57 to 0.86, p=0.002). Lacerations/abrasions declined by 42% (95% CI 0.39 to 0.85), concussions by 29% (95% CI 0.46 to 1.09), contusions by 18% (95% CI 0.43 to 1.55) and facial fractures by 16% (95% CI 0.55 to 1.28).

Conclusions This rule change appeared to reduce the risk of head injuries in men's professional football.

INTRODUCTION

A unique feature of football (soccer) is the intentional use of the head to play the ball. Head collisions with an opponent player are inevitable with existing rules. Head injuries may also be caused by unintended or unprepared heading the ball, by kicking against the head or by contact between the head and elbow/arm.[1–7] Prospective studies on head and neck injuries identified the unfair use of the upper extremity as a significant cause of head and neck injuries.[1 8]

Based on the analyses of injury mechanisms of head injuries during the FIFA World Cups (1998–2004),[8 9] the International Football Association Board (IFAB) altered the law of the game in 2006 so that direct and deliberate 'elbows to head' were punished with a red card.

We therefore aimed to (1) describe the most common mechanisms leading to head injuries (in matches only) in elite male football players and (2) measure the effect of the rule change in the 2006/07 season on head injuries.

METHODS

Study sample and design

A retrospective analysis of injury incidence rates (IRs) and injury mechanisms of head injuries in the first German Male Bundesliga was conducted for the seasons 2000/01–2012/13. We employed a retrospective comparison between seasons before the rule change and seasons afterwards. The rule change (penalising intentional elbow–head contacts with a red card) was introduced at the beginning of the 2006/07 season. In the present study this season was excluded from the analysis to ensure that referees and players became accustomed to the new rule. The analysis included 34 games per team in the regular season as well as games in official national and international competitions.

Neither Research Ethics Board approval nor the registration on clinicaltrials.gov was required for this study as all data were collected from public sources.[10]

Data collection

Data collection followed an a priori protocol and analysis plan. Head injuries, including publicly available clinical information (diagnosis and time loss), were identified by a structured search in the German football magazine 'kicker Sportmagazin' (all issues available online), which is published twice weekly with one journalist being responsible for one club and having contact with the club every day. The magazine presents injury reports. Additionally, a free-text search with defined search terms was conducted. For those injuries with an unknown outcome (eg, towards the end of the season), the mean time loss for the particular diagnosis in the present database was considered. Only match injuries were analysed. The injury mechanisms were captured on video recordings and analysed by two different investigators (sport scientists).[8 10 11] Disagreements were discussed in a consensus meeting with a third investigator (medical doctor). The video recordings were re-evaluated and a final decision was made by the third investigator.[1] Head injuries with no video recording available were classified as unknown injury mechanism and accounted for 18%.

Incident assessment

Observational criteria of head impact events during matches are listed in table 1. These defined criteria

Table 1 Points of measurement for the retrospective analyses of head impact events during matches

Injury causation	▶ contact with opponent ▶ contact with team mate ▶ no contact with player ▶ unknown
Injury mechanisms	▶ head–head ▶ hand–head; arm (forearm and upper arm)–head; elbow–head; shoulder–head ▶ pelvis–head; trunk–head ▶ foot–head; knee–head; lower leg–head; thigh–head ▶ ball–head; ground–head; advertising boards, goalpost, corner flag–head
Point of contact on the injured player's head/neck	▶ front ▶ side ▶ back ▶ top
Tackle direction	▶ from behind ▶ from the side ▶ from the front ▶ no tackling

are in accordance with the analyses of injury mechanisms that have previously been published.[8 11 12] Head injuries without video recordings are included in the analyses referring to total numbers and percentages.

Injury assessment

The football magazine 'kicker Sportmagazin' provided all relevant data on diagnosis such as concussions/traumatic brain injuries (TBI), contusions, facial fractures, lacerations/abrasions. The diagnoses were forwarded by team officials. Fractures of the zygomatic bone and skull (eg, base of the skull, calvaria and frontal sinus) as well as head contusions (to the skull and zygomatic bone only) were additionally grouped as 'suspected concussions' (independent from the original injury). Injuries with an unclear description and unknown diagnosis were categorised as 'other injury'. In case an injury encompassed more than one diagnosis, the more severe injury was recorded. The severity of injuries was based on the time loss according to the consensus statement published previously[13]: slight (time loss 0 days); minimal (1–3 days); mild (4–7 days); moderate (8–28 days); severe (>28 days).

Match exposure

Match exposure was recorded via online sources on football statistics and calculated using the following calculation[13]: number of official games x number of players on the field x duration of the game in hours. Official games included all season games, different cup games (eg, DFB-Cup) and international games (eg, Champions League). Extra time in knock out games was also considered. Games of the national teams were not included.

Inter-rater reliability

Two observers independently screened the video recordings using a standardised evaluation sheet. The inter-rater reliability was 87%.

STATISTICS

All statistical analyses were performed with Windows Excel 2010. IRs were calculated with the following formula: incidence = (number of injuries/hours of match exposure)×1000. For the IRs, 95% CIs were calculated as follows[14]:

Lower 95% CI = Incidence/$e^{1.96\times(\text{square root }[1/\text{number of incidents}])}$

Upper 95% CI = Incidence * $e^{1.96\times(\text{square root }[1/\text{number of incidents}])}$

Injury incidences before and after the rule change were considered significant if the 95% CI of the incidence rate ratio (IRR) did not include 1.0 and if the p value of the z-statistics was <0.05 (significance level for the α-error).[15 16] Descriptive data such as injury characteristics are presented as absolute numbers and percentages in parentheses.

RESULTS

Exposure and injury incidence rates (IRs)

Exposure and IRs are shown in table 2. The total exposure over the 13-season period was 160 413 hours. A total of 356 head injuries occurred of which 92% were time loss injuries. The IR for each season is shown in figure 1. The IR for head injuries was 2.22 (95% CI 2.00 to 2.46) per 1000 match hours. Lacerations/abrasions were the most common head injuries (33%); concussions/TBIs and facial fractures accounted for 25% each; and contusions (12%) and 'other injuries' (5%) were the least frequent injuries. 15% of all head injuries accounted for suspected concussions. The highest average time loss (14±12 days, median 9 days) was observed in facial/head fractures, followed by concussions/TBIs (11±10 days, median 7 days), head contusions (5±4 days, median 4 days) and lacerations/abrasions (4±4 days, median 3 days).

The comparison before and after the rule change in 2006 is shown in figure 2 and table 2. There was a lower number of head injuries in the seasons after the rule change (2007/08–2012/13) compared with before (2000/01–2005/06).

Injury mechanism

The detailed injury mechanisms are presented in table 3. The IRR for the three most frequent injury mechanisms for the first six seasons (2000/01–2005/06) versus the last six seasons (2007/08–2012/13) was 0.86 (95% CI 0.60 to 1.25, p=0.43) for head–head, 0.77 (95% CI 0.46 to 1.29, p=0.32) for elbow–head and 0.71 (95% CI 0.34 to 1.49, p=0.37) for foot–head.

Point of contact on the head and tackle direction

More head impacts involved the side in the seasons 2007/08–2012/13 compared with 2000/01–2005/06 (IRR 2.23, 95% CI 1.30 to 3.84, p=0.004). The back of the head was significantly more often affected in the first six seasons (IRR 0.08, 95% CI 0.01 to 0.65, p=0.017). There was no difference for front and top of the head contacts. There was no significant difference in tackle direction before and after the rule change.

DISCUSSION

After the rule change that introduced the red card in 2006, the overall number of head injuries decreased by about 29%. Lacerations/abrasions declined by 42%, and there were also reductions in concussions/TBI (29%), contusions (18%) and facial fractures (16%). The injury mechanism elbow–head was reduced by about 23%.

Epidemiology of head injuries in professional football

Compared with other contact sports such as rugby, American football or ice hockey, the IRs of head injuries in elite football are low.[1 17–19] Injury rates in training are considerably lower than match and overall (comprising match and training injuries) rates.[20] Nilsson *et al*[18] reported a 38-fold higher rate of head

Table 2 Comparison of injury characteristics of head injuries between the seasons 2000/01–2005/06 and 2007/08–2012/13

	2000/01–2012/13	IR of 1000 match hours (95% CI)	2000/01–2005/06	IR of 1000 match hours (95% CI)	2007/08–2012/13	IR of 1000 match hours (95% CI)	IRR (95% CI)	p Value
Match exposure (hours)	160413		74 519.5		73 749.5			
Head injuries (number)	356	2.22 (2.00 to 2.46)	196	2.63 (2.29 to 3.03)	138	1.87 (1.58 to 2.21)	0.71 (0.57 to 0.86)	**0.002**
Concussions/TBIs	90	0.56 (0.46 to 0.69)	50	0.67 (0.51 to 0.88)	35	0.48 (0.34 to 0.66)	0.71 (0.46 to 1.09)	0.12
Facial/head fractures	89	0.56 (0.45 to 0.68)	48	0.64 (0.49 to 0.86)	40	0.54 (0.40 to 0.74)	0.84 (0.55 to 1.28)	0.42
Contusions	42	0.26 (0.19 to 0.35)	21	0.28 (0.18 to 0.43)	17	0.23 (0.14 to 0.37)	0.82 (0.43 to 1.55)	0.54
Lacerations/abrasions	119	0.74 (0.62 to 0.89)	70	0.94 (0.74 to 1.19)	40	0.54 (0.40 to 0.74)	0.58 (0.39 to 0.85)	**0.006**
Other injuries	16	0.10 (0.06 to 0.16)	7	0.09 (0.05 to 0.20)	6	0.08 (0.04 to 0.18)	0.87 (0.29 to 2.58)	0.80
Suspected concussions	53	0.33 (0.25 to 0.43)	27	0.36 (0.25 to 0.53)	26	0.35 (0.24 to 0.52)	0.97 (0.57 to 1.67)	0.92
Time loss head injuries (n)	329	2.05 (1.84 to 2.29)	173	2.32 (2.00 to 2.70)	138	1.87 (1.58 to 2.21)		
Mean±SD time loss (days)	9±10		9±10		9±10			
Median time loss (days)	5		6		5			
Range of time loss (days)	0–62		0–62		0–52			
1–3 days	73		37		31			
4–7 days	152		80		65			
8–28 days	89		47		36			
>28 days	15		9		6			
No time loss head injuries (n)	27	0.17 (0.12 to 0.25)	23	0.31 (0.21 to 0.46)	0	–		

IR, incidence rate; IRR, incidence rate ratio; TBI, traumatic brain injury.
Suspected concussion, head contusions and fractures of the zygomatic bone and skull (eg, basal skull, calvaria and frontal sinus) excluding mandibular and nasal bone fractures, lacerations/abrasions and neck contusions.

injuries during matches compared with training and a 78-fold higher rate of concussions. Fuller's work that led to the rule change in 2006[8] reported an IR for head injuries of 12.5/1000 match hours with regard to international tournaments. The IR of head injuries is highest in matches of international tournaments[8 21] and can reach IRs for muscle injuries of approximately 10/1000 match hours[15 22] and joint injuries of 8/1000 match hours.[15]

Injury mechanisms and rule change

A rule was changed punishing direct and intentional elbow to head hits with a red card. All injury types were reduced after this rule change, demonstrating that rule changes in professional football may be an effective means to prevent injury. Nevertheless, a considerable variability of injury incidences over the 13-year period became apparent (figure 1). A longitudinal investigation of head injuries comprising, for example, 10+ years after the rule change is required to allow for a judgement on whether the rule change has a permanent effect.

Head injuries caused by elbow to head movements were less frequent after the rule change (IRR 0.77). This finding is in line with the results of Bjørneboe *et al*[23] who found a reduction in the rate of head incidents as well as head incidents caused by arm to head contact after stricter interpretation of the rules. Adding season 2006/07 to the six seasons after the rule change decreased the IRR from 0.77 to 0.66. It remains unknown how much the missing video recordings would have changed the injury mechanism elbow–head.

Extending current literature, any kind of body contact with another player was the most frequent cause of head injuries (as opposed to contact with the ground, posts, etc). Although the IR of head injuries was lower after the rule change, the percentage of contact-related injuries remained high. Potentially, there were fewer fouls or a greater commitment to fair play during header duels after the rule change, but it is impossible to reduce or even eliminate any contact between players as this is a fundamental part of football.

Head–head contact was the most frequent injury mechanism, followed by elbow–head and foot–head both before and after the

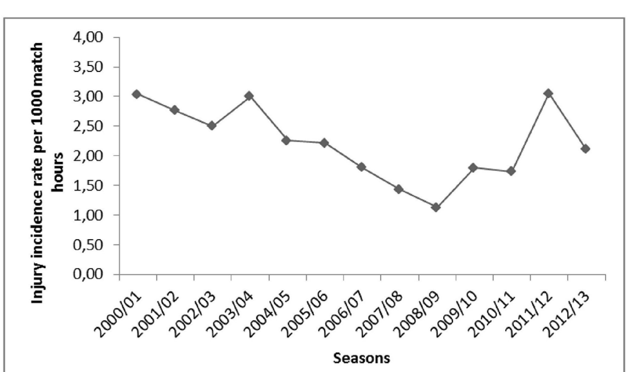


Figure 1 Head injury variability in 13 seasons (2000/01–2012/13).

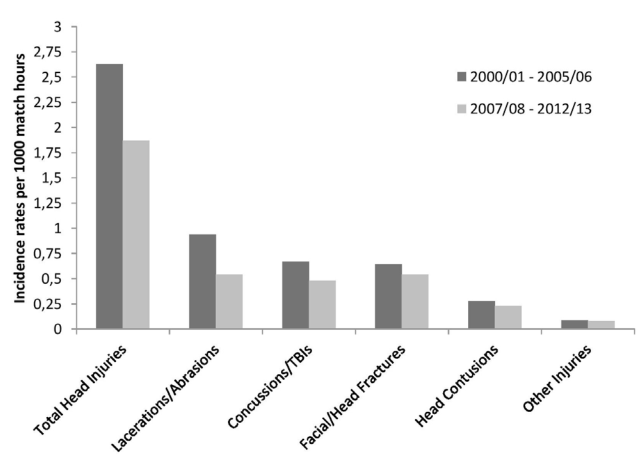


Figure 2 Head injury incidence rates for the seasons 2000/01–2005/06 and 2007/08–2012/13.

Table 3 Video analysis of injury mechanisms of head injuries

	2000/01–2012/13	IR of 1000 match hours (95% CI)	2000/01–2005/06	IR of 1000 match hours (95% CI)	2007/08–2012/13	IR of 1000 match hours (95% CI)
Head injuries (n)	356 (100)	2.22 (2.00 to 2.46)	196 (100)	2.63 (2.29 to 3.03)	138 (100)	1.87 (1.58 to 2.21)
Head injuries on video recordings	292 (82)		148 (75)		117 (85)	
Contact with opponent	245 (69)	1.53 (1.35 to 1.73)	133 (68)	1.79 (1.51 to 2.12)	111 (80)	1.51 (1.25 to 1.81)
Contact with team mate	26 (7)	0.16 (0.11 to 0.24)	11 (5)	0.15 (0.08 to 0.27)	2 (1.5)	0.03 (0.01 to 0.11)
No contact with player	8 (2)	0.05 (0.03 to 0.10)	4 (2)	0.05 (0.02 to 0.14)	4 (3)	0.05 (0.02 to 0.15)
Unknown	79 (22)	0.49 (0.40 to 0.61)	48 (25)	0.64 (0.49 to 0.86)	21 (15.5)	0.29 (0.19 to 0.44)
Injury mechanism						
Head–head	120 (34)	0.75 (0.63 to 0.90)	61 (31)	0.82 (0.64 to 1.05)	52 (38)	0.71 (0.54 to 0.93)
Elbow–head	60 (17)	0.37 (0.29 to 0.48)	34 (17)	0.46 (0.33 to 0.64)	26 (19)	0.35 (0.24 to 0.52)
Foot–head	32 (9)	0.20 (0.14 to 0.28)	17 (9)	0.23 (0.14 to 0.37)	12 (9)	0.16 (0.09 to 0.29)
Knee–head	15 (4)	0.09 (0.06 to 0.16)	7 (4)	0.09 (0.05 to 0.20)	7 (5)	0.10 (0.05 to 0.20)
Hand–head	14 (4)	0.09 (0.05 to 0.15)	7 (4)	0.09 (0.05 to 0.20)	7 (5)	0.10 (0.05 to 0.20)
Arm–head	9 (3)	0.06 (0.03 to 0.11)	6 (3)	0.08 (0.04 to 0.18)	3 (2)	0.04 (0.01 to 0.13)
Shoulder–head	8 (2)	0.05 (0.03 to 0.10)	6 (3)	0.08 (0.04 to 0.18)	2 (1)	0.03 (0.01 to 0.11)
Pelvis–head	5 (1)	0.03 (0.01 to 0.07)	4 (2)	0.05 (0.02 to 0.14)	1	0.01 (0.00 to 0.10)
Trunk–head	5 (1)	0.03 (0.01 to 0.07)	1	0.01 (0.00 to 0.10)	3 (2)	0.04 (0.01 to 0.13)
Lower leg–head	3 (1)	0.02 (0.01 to 0.06)	0	-	0	-
Thigh–head	1	-	0	-	0	-
Ground–head	9 (3)	0.06 (0.03 to 0.11)	6 (3)	0.08 (0.04 to 0.18)	1	0.01 (0.00 to 0.10)
Ball–head	6 (2)	0.04 (0.02 to 0.08)	3 (1)	0.04 (0.01 to 0.13)	3 (2)	0.04 (0.01 to 0.13)
Bank–head	1		0	-	0	-
Point of contact on injured player's head/neck						
Front	207 (58)	1.30 (1.13 to 1.48)	117 (60)	1.57 (1.31 to 1.88)	90 (65)	1.22 (0.99 to 1.50)
Side	61 (17)	0.38 (0.30 to 0.49)	19 (5)	0.26 (0.16 to 0.40)	42 (30)	0.57 (0.42 to 0.77)
Back	13 (4)	0.08 (0.05 to 0.14)	12 (3)	0.16 (0.09 to 0.28)	1	0.01 (0.00 to 0.10)
Top	5 (1)	0.03 (0.01 to 0.07)	2	0.03 (0.01 to 0.11)	3 (2)	0.04 (0.01 to 0.13)
Tackle direction						
From the side	114 (32)	0.71 (0.59 to 0.85)	55 (28)	0.74 (0.57 to 0.96)	59 (43)	0.80 (0.62 to 1.03)
From the front	105 (30)	0.66 (0.54 to 0.79)	54 (28)	0.73 (0.56 to 0.95)	51 (37)	0.69 (0.53 to 0.91)
From behind	51 (14)	0.32 (0.24 to 0.42)	32 (16)	0.43 (0.30 to 0.61)	19 (14)	0.26 (0.16 to 0.40)
No tackling	5 (2)	0.03 (0.01 to 0.07)	3	0.04 (0.01 to 0.13)	2 (1)	0.03 (0.01 to 0.11)

% in parentheses; Values <1% are not mentioned; IR, incidence rate; 2000/01-2012/13 includes season 2006/07.

rule change. The present results for head–head contact (34%) match with previously published data reporting 30–33%.[1 8 24 25] The data of Delaney *et al*[24] matched the results of this study with regard to elbow–head events (17% in both studies). Andersen *et al*[1] reported a higher number of 34%. The upper extremity (including hand and arm) caused 35%[8] and 38%,[25] respectively, of head injuries. It should be noted that the latter studies were performed before the adaptation of the law in 2006 and might therefore have demonstrated higher numbers compared with the results of the present study.

Heading is a unique feature of football. The attempt to head the ball was the predominant action performed by both injured and non-injured players. Interestingly, no head injury occurred after intentional heading of the ball, indicating that the skill 'heading' is well trained. The effects of repetitive heading without resulting in concussions remain to be elucidated and were not within the scope of this project. Literature reviews on heading report conflicting results,[5 7 26 27] but need to be interpreted with caution as the differentiation between (serial) concussions and sub-concussive blows is mandatory at this point.

Methodological considerations

All retrospective studies have some risk of bias and allow limited causal inference. Other factors, besides the rule change, may have contributed to the reduction of head injuries. Omitting season 2006/07 was considered to most appropriately carve out the potential effect of the rule change.

Interpreting head injuries is difficult as injuries with (accompanying) concussion symptoms are often not diagnosed as concussion or TBI but, for example, as head contusion only. Concussions can easily be overlooked by laypersons and even medical staff due to mild symptoms or even masked post-injury signs by the player himself. Donaldson *et al*[10] added facial fractures, excluding the nasal bone, to the category of concussion under the subheading 'suspected concussion'. Their rationale was that substantial force is required to cause a facial fracture and this could also be associated with an intracranial injury.[28 29] According to this, the estimated number of unreported cases of concussions and TBIs is even higher than has been reported,[17 18] but remains uncertain. We used the diagnosis 'suspected concussion' as well. Facial fractures were included only if they affected the zygomatic bone or the skull. Additionally, head contusions to the aforementioned bones counted towards this category. Injuries affecting the nasal bone such as fractures or contusions, mandibular fractures and lacerations/abrasions were excluded from that category as such injuries may not necessarily transmit the force of impact directly to the cranium and the brain respectively. Certain lacerations/abrasions (if located directly on the skull) might be forceful enough to cause concussions and may also be classified as minor intracranial injuries. On the other hand, injuries retrospectively assigned to the category 'suspected concussion' might not have resulted in concussion-like impairments. Thus, the error of estimation for 'suspected concussion' seems likely to be somewhat balanced. Some head injuries (7%) encompassed more than one diagnosis. In these cases the more severe injury was recorded. These more comprehensive injuries might prolong the anticipated recovery time, and thus the time loss and the return to play.

Return to play after sustaining a concussion was previously recommended after 7–10 days.[6] However, symptoms may persist even longer.[30 31] The mean time loss after concussion and TBI during the 13-season period of the study was 11 days. This is consistent with the data of Nilsson *et al*.[18] However, half of the present concussed players returned to play in less than 1 week despite current consensus recommendations that emphasise a sufficient rest period to achieve full recovery.[6] Our data suggest that at least some players may have returned to play prematurely after concussion, but our study was not designed to address such a question.

In this analysis 82% of the head injuries were available on video recordings and can be regarded as excellent. This percentage is in accordance with a previous study in which 80% were identified.[12] Other video analysis-based studies identified about 66%[8] and 65%.[1] The inter-rater reliability of 87% can be regarded as good compared with previously published studies of 85%[8] and 95%.[9] Only 18% of the head injury events were not available on video recordings. We see the video evidence and analysis as a strength of this study.

A strength of data collection in professional male football is the accuracy of time loss recording as full-time football players are seen daily by the medical staff. The football magazine 'kicker Sportmagazin' is published twice weekly with one journalist being responsible for one club and usually having contact with the club every day. Similarly, online open-source sports databases and the diagnoses being communicated to these media by team officials have previously been used to gather information on injuries in professional football.[17 32] Yet the present data were not validated with medical records by each team's medical departments.

CONCLUSION

Most head injuries in professional male football are caused by head–head and elbow–head contacts. After the rule change, the IR for elbow–head incidents decreased by 29% as well as the IRs for all head injury types. Rule changes in football may be an appropriate means of achieving a reduction in head injuries.

What are the new findings?

- The injury incidence rate for head injuries in German professional football is lower than in high-risk sports
- Head to head and the unfair use of the elbow are the main injury mechanisms leading to head injuries
- Rule changes as an injury prevention strategy appear to reduce the occurrence of head injuries
- Lacerations/abrasions and concussions/traumatic brain injuries decreased the most

How might it impact on clinical practice in the near future?

- As head injuries bear the potential risk of long-term health sequelae, the identification of injury mechanisms is essential to develop preventative means in the future
- The present data may be helpful for decisions on when to return to play

Acknowledgements The authors wish to thank the 'kicker Sportmagazin' magazine for granting access to their online issues. The video recordings were obtained from the official German Football League (Die Liga – Fußballverband (DFL)).

Contributors TM, FB and CR were responsible for the conception and design of the study. FB was responsible for data collection over the study period. FB conducted the statistical analyses. FB, TT and KadF conducted the video analyses. FB wrote the paper. The draft of the paper was critically revised by CR, KadF and TM.

Funding This study was funded by the German Federal Institute of Sports Science.

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1 Andersen TE, Arnason A, Engebretsen L, *et al*. Mechanisms of head injuries in elite football. *Br J Sports Med* 2004;38:690–6.
2 Boden BP, Kirkendall DT, Garrett WE. Concussion incidence in elite college soccer players. *Am J Sports Med* 1998;26:238–41.
3 Dvorak J, Junge A, Injuries F, *et al*. A review of the literature. *Am J Sports Med* 2000;28:S3–S9.
4 Kirkendall DT, Jordan SE, Garrett WE. Heading and head injuries in soccer. *Sports Med* 2001;31:369–86.
5 Maher ME, Hutchison M, Cusimano M, *et al*. Concussions and heading in soccer: a review of the evidence of incidence, mechanisms, biomarkers and neurocognitive outcomes. *Brain Inj* 2014;28:271–85.
6 McCrory P, Meeuwisse WH, Aubry M, *et al*. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med* 2013;47:250–8.
7 Spiotta AM, Bartsch AJ, Benzel EC. Heading in soccer: dangerous play? *Neurosurgery* 2011;70:1–11.
8 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 I):i3–i9.
9 Fuller CW, Smith GL, Junge A, *et al*. The influence of tackle parameters on the propensity for injury in international football. *Am J Sports Med* 2004;32:43S–53.
10 Donaldson L, Asbridge M, Cusimano MD. Bodychecking rules and concussion in elite hockey. *PLoS One* 2013;8:e69122.
11 Tscholl P, O'Riordan D, Fuller CW, *et al*. Tackle mechanisms and match characteristics in women's elite football tournaments. *Br J Sports Med* 2007;41 Suppl 1:i15–i19.
12 Tscholl P, O'Riordan D, Fuller CW, *et al*. Causation of injuries in female football players in top-level tournaments. *Br J Sports Med* 2007;41 Suppl 1:i8–i14.
13 Fuller CW, Ekstrand J, Junge A, *et al*. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Br J Sports Med* 2006;40:193–201.
14 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;40:767–72.
15 Aus der Fünten K, Faude O, Lensch J, *et al*. Injury characteristics in the German professional male soccer leagues after a shortened winter break. *J Athl Train* 2014;49:786–93.
16 Fuller CW, Dick RW, Corlette J, *et al*. Comparison of the incidence, nature and cause of injuries sustained on grass and new generation artificial turf by male and female football players. Part 1: match injuries. *Br J Sports Med* 2007;41 Suppl 1:i20–i26.
17 Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: the UEFA injury study. *Br J Sports Med* 2011;45:553–8.

18 Nilsson M, Hägglund M, Ekstrand J, *et al*. Head and neck injuries in professional soccer. *Clin J Sport Med* 2013;23:255–60.
19 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;39:542–6.
20 Ekstrand J, Hägglund M, Kristenson K, *et al*. 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;47:732–7.
21 Junge A, Dvorak J. Injury surveillance in the World Football Tournaments 1998-2012. *Br J Sports Med* 2013;47:782–8.
22 Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). *Am J Sports Med* 2011;39:1226–32.
23 Bjørneboe J, Bahr R, Dvorak J, *et al*. Lower incidence of arm-to-head contact incidents with stricter interpretation of the laws of the game in norwegian male professional football. *Br J Sports Med* 2013;47:508–14.
24 Scott Delaney J, Puni V, Rouah F. Mechanisms of injury for concussions in university football, ice hockey, and soccer: a pilot study. *Clin J Sport Med* 2006;16:162–5.
25 Withnall C, Shewchenko N, Gittens R, *et al*. Biomechanical investigation of head impacts in football. *Br J Sports Med* 2005;39 Suppl 1:i49–i57.
26 Niedfeldt MW. Head injuries, heading, and the use of headgear in soccer. *Curr Sports Med Rep* 2011;10:324–9.
27 Rodrigues AC, Lasmar RP, Caramelli P. Effects of soccer heading on brain structure and function. *Front Neurol* 2016;7:1–11.
28 Pappachan B, Alexander M. Correlating facial fractures and cranial injuries. *J Oral Maxillofac Surg* 2006;64:1023–9.
29 Keenan HT, Brundage SI, Thompson DC, *et al*. Does the face protect the brain? A case-control study of traumatic brain injury and facial fractures. *Arch Surg* 1999;134:14–27.
30 Harmon KG, Drezner JA, Gammons M, *et al*. American Medical Society for Sports Medicine position statement: concussion in sport. *Br J Sports Med* 2013;47:15–26.
31 McCrea M, Guskiewicz K, Randolph C, *et al*. Incidence, clinical course, and predictors of prolonged recovery time following sport-related concussion in high school and college athletes. *J Int Neuropsychol Soc* 2013;19:22–33.
32 Leventer L, Eek F, Hofstetter S, *et al*. Injury patterns among elite football players: a media-based analysis over 6 seasons with emphasis on playing position. *Int J Sports Med* 2016;37:898–908.

BJSM

Head injuries in professional male football (soccer) over 13 years: 29% lower incidence rates after a rule change (red card)

Florian Beaudouin, Karen aus der Fünten, Tobias Tröß, Claus Reinsberger and Tim Meyer

Br J Sports Med published online June 23, 2017