Risk of head injury in football due to heading duels – A video analysis of 11.514 headings in elite football

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Research article

Keywords: Heading, football, sports medicine, concussion, video analysis

Posted Date: February 8th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1177080/v1>

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Abstract

Introduction: Heading is an integral part of football and frequent media reports and previous studies about potential danger of heading and head trauma in football fuelled discussions. Epidemiological data and video analyses regarding the frequency of headings and associated head injuries are still missing in adult elite football.

Methods: In a prospective cohort study in the fourth German football league, 100 official matches of the 2015-2016 season were assessed by means of video analysis and a standardized protocol. Head injuries were documented and confirmed by standardised epidemiological injury reports of the teams.

Results: Overall, 11,514 headings were analysed in detail. Video analysis yielded a mean of 5.7 headings per player and match (SD: 1.2; min: 0; max: 15). Heading was predominantly performed with the frontal part of the head (76.8%), and nearly two thirds of all headings occurred during defending (65.8%). 71.0% of all headings occurred during tacklings, of which 71.9% involved body contact with the opponent player. Video analysis yielded 31 critical incidents (CI) on the head due to heading (incidence: 1.02 per 1000 h match exposure and player). 29 CIs occurred during heading duels (Odds ratio: 5.91), 30 CIs with body contact (odds ratio: 28.8) and 6 CIs with elbow contact (odds ratio: 6.13).

Conclusion: Heading duels, especially with body contact and high elbow, are important risk factors for head injuries and key factor for prevention strategies. The impact of 5.7 headings per match on players' brain should be investigated in further research.

Introduction

Football is a unique type of ball sports that allows its players to use the head for controlling, passing and shooting a ball [1–3]. For more than 20 years, there has been a growing discussion about the potential harm of headings for the brain [2, 4–9]. This discussion was fueled by the first studies describing several structural and biochemical changes in former football players, even in those without a history of concussion [7, 8, 10, 11], and by the ban on headings for under 13-year old children by the US Soccer Federation (USSF) in 2015. Especially long-term consequences of headings such as neuro-psychological changes have been frequently, but mostly cross-sectionally been investigated [10, 15–17].

Epidemiological data on the impact of heading on the brain in football are sparse, and most experiences and evident data on long-term structural changes are derived from other contact sports such as ice hockey or American football. Reports on neurological and neuropsychological impact of headings are very rare in the current literature. The few interventional studies available mostly describe heading sessions of about 10 to 15 minutes [42, 43] and estimated rate of 50 to 100 headings per player. However, it is unclear whether the designs of these interventional studies allow an interpretation of the impact of heading in practical football routine. The present study investigated for the first time heading and head injuries in elite football by means of standardised video analysis. This study evaluated the current

frequencies of headings and head trauma in football matches and the impact of heading duels on the occurrence of head injuries.

Methods

This prospective cohort study investigated the fourth German football league by means of video analysis and injury reports during the 2015-2016 season. Video analysis has been identified as a useful tool for characterising headings in detail and for identifying critical incidents leading to head injuries in football [1, 24]. The investigated fourth league included 18 teams with professional football players. The Regional Football Association of Bavaria (BFV) provided the television recordings of all 306 matches of the 2015-2016 season for video analysis. The recordings had been filmed by at least one camera fixed to the grandstand of each football stadium. All injuries including head injuries of the entire season were monitored by means of a standardised injury questionnaire issued to the players and medical staff of each of the 18 teams. Injuries were documented according to previously published injury definitions and data collection standards in football [18, 25]. A representative, randomly chosen sample of 100 matches was investigated by video analysis. At first, videos were reviewed to identify the frequency of headings. Every header was then analysed by means of a standardised video analysis protocol developed prior to the study and used here for the first time (see figure 1). In this protocol, 18 characteristics of heading were queried including the duelling situation, the areas of body contact or the elbow position during the heading. Furthermore, the type, distance and angle of the ball to the player were documented as well as the impact surface of the ball on the head and any concomitant jumps or movements of the players. Headings were viewed in slow-motion and freeze-frame in a standardised manner to allow a precise analysis of the header. Unclear situations were immediately discussed by the study team that consisted of at least three reviewers, blinded to each other. Because of differences in distances and position of the video camera in each stadium, distances or angles on the video could not precisely be measured. In such cases, auxiliary quantities such as the size and boundaries of the field, penalty areas or centre circles were used to interpret the different heading situations (Fig. 1).

Additionally, critical incidents (CI) on the football field according to the criteria first published by Anderson et al. 2004 [1] and further developed by Bjorneboe et al. 2014 [26] were separately analysed. According to the previously published standard, a CI is a situation in which the player appears to be hit. In the present study, the focus was on hits to the head, if the match was interrupted by the referee and if one of the players involved in the tackling was lying on the ground for more than 15 sec or had to be carried off. Every head trauma observed on video was assessed by specific items such as the starting situation and its triggers, the contact area on the head and co-injured body areas. Position on field and evaluation by the referees were also documented. Each CI was viewed several times at different slow-motion speeds and freeze-frames. Any uncertain situation was managed as described above. After match completion, each reported CI was cross-referenced with the standardised epidemiological injury investigation over the season, which was conducted prospectively.

Statistics

Injury incidence was calculated by the number of injuries divided by hours of match exposure multiplied by 1000. Descriptive data such as injury characteristics are presented as absolute numbers and percentages. Rates of contact injuries between different types of heading situations were compared by chi-square test of independence. Odds ratios with corresponding 95% confidence intervals were calculated as effect estimates. A p-value <0.05 was considered as statistically significant. All analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Video analysis yielded 11,514 headings in 9229 match minutes (115.1 headings per match/ standard deviation (SD): 24.4; 1.2 headings per match minute/SD: 0.3, see Table 1). With the exception of goalkeepers, who only performed 7 headings in 100 matches, the mean heading rate per field player and match was 5.7 (SD: 1.2). While many players had 0 headings in football matches, was the highest number of headings per match of one player 15. With regard to the position on field, defenders showed the highest percentage of headings (44.1%, 5084 headings) followed by strikers with 12.5% (1435 headings) and midfield players with 35.3% (4019 headings, see figure 2). Most headings were performed after high passes (32.0%), goal kicks (18.4%) and previous headings (15.7%). Headings after corners (4.7%), free kicks (8.0%) and crosses (5.0%) were less frequent. In 3.8% (440) of headings the elbow was at or above shoulder-height. The majority of headings was recorded in the midfield area of the football field (5971, 52.8%). The total rate of headings in the penalty area (2364, 20.9%) was lower than in the outer tracks (2973 headings, 26.3%; Fig. 2). About 71% of all headings occurred during tackling, of which 71.9% involved physical contact between the players. Less than 5% of all headings involved body contact with more than one player. About 3% of all headings were judged as a foul by the referee.

Table 1
Selected characteristics of the analysed headings in 100 matches

	total number (percentage)
Position of player:	5,084 (44.1%)
- defender	4,019 (35.3%)
- midfield player	1,435 (12.5%)
- striker	
Area on field:	5,971 (52.8%)
- midfield	2,973 (26.3%)
- outer track	2,364 (20.9%)
- penalty area	
Minute of the match:	1,980 (17.2%)
- min 0 to 15	1,871 (16.3%)
- min 16 to 30	1,953 (17.0%)
- min 31 to 45	1,898 (16.5%)
- min 46 to 60	1,704 (14.8%)
- min 61 to 75	2,101 (18.2%)
- min 76 to 90	
Playing situation:	9,228 (81.4%)
- free play	938 (8.3%)
- free kick	628 (5.5%)
- throw-in	542 (4.8%)
- corner	
Type of heading:	9,402 (81.9%)
- active heading	1,389 (12.1%)
- sliding ball	290 (2.5%)
- pick-up or running with ball	115 (1.0%)
- return pass	75 (0.7%)
- diving header	62 (0.5%)
- unintentional head hit after free kick	

	total number (percentage)
Affected head area:	8,848 (78.5%)
- frontal	2182 (19.4%)
- parietal	163 (1.4%)
- occipital	80 (0.7%)
- temporal	
Elbow position:	11,055 (96.2%)
- below shoulder-height	432 (3.7%)
- at shoulder-height	7 (0.1%)
- above shoulder-height	
Head position:	11,176 (97.6%)
- at or above pelvic area	247 (2.4%)
- below pelvic area	
Match score:	5,008 (44.6%)
- draw	3,161 (28.1%)
- own team leading	3,067 (27.3%)
- opponent team leading	
Ball possession:	7,577 (66.2%)
- opponent team	3,865 (33.8%)
- own team	
Heading duel:	8,178 (71.1%)
- yes	3,324 (28.9%)
- no	
Body contact:	5884 (51.2%)
- direct contact	5616 (48.8%)
- no contact	

Video analysis identified 45 CIs (0.39%) due to heading (see Table 2). The head was the most affected body area (31 players, 68.9%) followed by the back (6 players, 13.3%) and the ankles (4 players, 8.9%). The CI rate for the head per match and player was 0.0016 (1.02 per 1000 h match exposure and player). The distribution of CIs due to heading regarding the playing positions was similar to that of the heading

rates with defenders being the most affected players (15 CI, 48.4%; see figure 3). 29 CIs (93.5%) involved a time-out of which 5 (16.1%) resulted in the substitution of the injured player. 29 of 31 CIs (93.5%) occurred in duelling situations, and 30 CIs (96.8%) involved active body contact. 13 of 31 CIs (41.9%) were judged as a foul by the referee, and 4 CIs (13.4%) resulted in a yellow or red card. 30 CI (5.1 CI per 1000 headings) resulted from 5884 (51.2%) headings with body contact, while 1 CI on the head occurred in 5616 (48.8%) headings without body contact (0.18 CI per 1000 headings; Odds ratio: 28.8; 95%-CI: 4.8, 1174; $p<0.001$). 29 CI (3.5 CI per 1000 headings) occurred in 8178 duelling situations (71.1%), while 2 CI resulted from 3334 non-dueling situations (28.9%) (0.6 CI per 1000 headings; Odds ratio: 5.91 95%-CI: 1.49, 51.15, $p=0.006$). 6 CI (13.7 CI per 1000 headings) were observed in 438 (3.8%) situations with elbow on or over shoulder height occurred, while 25 CI occurred in 11,055 (96.2%) headings without lifted elbow (2.3 CI per 1000 headings; Odds ratio: 6.13; 95%-CI 2.04, 15.40; $p<0.001$). When cross-referencing the CIs with seasonal injury reports of head injuries, 4 head injuries had been reported by the teams in the 100 investigated matches. 1 nasal fracture, 1 skin laceration and 2 concussions were diagnosed resulting in a concussion rate after heading of 0.017% and a concussion incidence of 0.065 per 1000 match hours and player.

Table 2
Selected characteristics of the 31 critical incidents on the head in
100 games

	total number (percentage)
Position of player:	15 (48.4%)
- defender	11 (35.5%)
- midfield player	5 (16.1%)
- striker	
Area on field:	19 (61.3%)
- midfield	7 (22.6%)
- outer track	5 (16.1%)
- penalty area	
Minute of the match:	0 (0)
- min 0 to 15	10 (32.3%)
- min 16 to 30	6 (19.3%)
- min 31 to 45	2 (6.4%)
- min 46 to 60	10 (32.3%)
- min 61 to 75	3 (9.7%)
- min 76 to 90	
Playing situation:	28 (90.3%)
- free play	2 (6.5%)
- free kick	1 (3.2%)
- corner	
Match score:	11 (36.7%)
- draw	10 (33.3%)
- opponent team leading	9 (30.0%)
- own team leading	
Basic action of the player:	28 (90.3%)
- air time	2 (6.5%)
- running	1 (3.2%)
- standing	

	total number (percentage)
Heading duel:	29 (93.5%)
- yes	2 (6.5%)
- no	
Body contact:	30 (96.8%)
- direct contact	1 (3.2%)
- no contact	
Affected head area:	10 (32.3%)
- occipital	8 (25.8%)
- facial	8 (25.8%)
- frontal	5 (16.1%)
-parietal	
Direction of attack:	11 (37.9%)
- back	11 (37.9%)
- front	6 (20.7%)
- side	1 (3.4%)
- both sides	
Contact to the ground:	27 (87.1%)
- no contact with ground	3 (9.7%)
- one leg	1 (3.2%)
- two legs	
Type of contact:	19 (61.3%)
- collision with opponent player	6 (19.4%)
- hit by opponent player (elbow)	3 (9.7%)
- none	1 (3.2%)
- collision with team player	1 (3.2%)
- collision with ball	1 (3.2%)
- hit by team player	

	total number (percentage)
Affect on player:	20 (64.5%)
- able to leave the field on both feet	9 (29.0%)
- no treatment	2 (6.5%)
- carried off	

Discussion

In the so far largest cohort study on video analysis of heading in football, this study provides detailed information on the incidence and development of headings in elite football. One important finding of this study was the quantification of heading per player and match with a mean of 5.7 or a maximum of 15 for one player during the match. The impact of heading on neurological or neuropsychological symptoms was previously published in experimental studies with significantly higher heading frequencies per intervention [11, 38–40, 44] than in this study yielding a need for a discussion on how the previous data is applicable to real game situations. The importance of this topic for sports medicine has been documented in several studies over the past few years and the increasing interest in the results of the international conference on concussion in sports. Previously published study results have indicated that heading in football may be dangerous for the brain, changing its microstructure and neurochemistry and effecting neurocognitive changes [7, 8, 10, 11, 27–29]. Additionally, the ban on heading for under 13-year olds by the US Soccer Federation (USSF) in 2015 has given a further impetus to the ongoing discussion about the harmfulness of heading, in particular because scientific evidence on the danger of heading in football is still lacking.

So far, epidemiological data on heading and head injuries in football are scarce [5, 6]. Detailed video analyses of headings and head injuries are rare, although such analyses are a commonly used analytical method for characterising specific situations in sports matches [1, 24, 32–37]. Several studies have concluded that traumatic brain injuries due to head trauma, especially when incurred several times within a short period of about 2 to 4 weeks, are a major risk factor for changes in the brain [12–14]. As this investigation showed, injuries to the head resulting from heading are rather rare in football compared to common injuries predominately affecting thighs, knees and ankle [18–20]. Head injuries, which also include midfacial lesions and fractures, account for 5 to 20 per cent of all reported injuries and have been recently considered an underrepresented problem in sports [46]. The total number of sports-related concussion is still often overlooked, in part because of the non-apparent clinical signs that are only revealed by a clinical examination that occasionally medical doctors are not proficient in. Especially at lower skills levels and in junior football there might not even be a medical team available to carry out such an examination [21]. This situation defines the urgent need for improved and sufficient injury prevention steps for head injuries of football players.

One other important finding of this study is that head injuries and CIs on the head directly result from heading duels, body contacts and still and also with lifted elbow. Head injuries are known to often occur during tackling, so that different strategies for preventing head injuries have been developed over the past few years [22, 23]. Rule modifications like the advice to ban a player for intentional elbow-to-head contact, have significantly reduced the rate of head injury [1, 3]. However, further strategies should be considered in connection with the results of this study, such as education in fair play in heading duels, avoiding fouls during tackling and training in correct heading techniques [21]. Above all, football players need to be informed about the possible consequences of head injuries to reduce their willingness of risking a contact between their head with the body of other players. Such education of football players may be an important factor for preventing head injuries in heading duels [47, 48].

With a rate of critical incidents and concussions in this study, the risk of sustaining concussion in football is much lower than in other sports such as Australian football, American Football or Ice hockey [35, 45]. Nevertheless, the total number of head injuries in football worldwide is substantial because of the high number of football players, since football is the most important sport worldwide. It is essential to reduce the number of head injuries and to eliminate the uncertainty of football players on this topic. Besides injury prevention of head injuries, both football players and staff should be further educated about the incidence, diagnostics, symptoms and first aid on field [48, 49]. The problem of late diagnosis or overlooked concussion [46] is still a problem in all team sports and should also be improved in football.

One other important result of this study is the low concussion rate of the injury statistics provided by the teams compared to the rate of CIs on the head documented by means of video analysis. According to the definition of a CI, only 2 concussions in 31 CIs to the head were verified in our video analysis. This situation may illustrate that minor head injuries are not gaining enough attention of the football players or other staff on field. Such potentially overlooked minor head injuries may not be worked up properly (for example by a detailed (neurological) examination) and may not receive sufficient treatment with adequate further clinical diagnostic work up or rest, so that players are at risk of sustaining recurrent hits on the head in further heading duels [49].

This study also has some limitations. In the fourth football league, television recordings are often only obtained by 1 video camera per match and football field. Evaluating heading and head trauma situations may therefore be different to football matches in professional football, in which football matches are continuously recorded by several cameras in different positions. Additionally, the transfer of our study results to other football subpopulations is somewhat limited. Professional players may even have better tackling abilities in headings duels than amateur or junior players. The different constitution of football players, especially of women and junior players, influence heading situations as well as the aetiology of injuries. These characteristics should be investigated in other subpopulations, for example by video analyses in the future. The incidence of heading and head trauma of football players is generally assessed by match and training exposure, whereas this study only included match exposure. Competitions as well as official matches are assumed to be associated with higher injury rates than

training sessions [31], but future research should also evaluate the rate of heading and concussion by video analysis with regard to training exposure. Heading duels have been shown to be major risk situations that mainly occur in matches; thus, they are preventable by reducing aggressiveness or risk taking in headings duels. In contrast, head injuries in training sessions may be prevented by reducing the number and intensity of heading duels or by increasing the awareness of players and staff regarding head injuries.

Conclusion

The maximum of headings in elite football is 15 per match. Mean heading rates of 5.7 per player and match in seem to be lower than previously reported in the literature. Head injuries as a result of heading occurred at an incidence rate of 1.02 per 1000 h match exposure and player and were specifically associated with heading duels, body contact and elbow hits. Future research is necessary to investigate heading and the frequency of head trauma in other football subpopulations to improve strategies for injury prevention.

Abbreviations

BFV	Bayrischer Fußball Verband (Bavarian Football Association)
CI	Critical incident
SD	Standard deviation
USSF	United States Soccer Federation
VBG	Verwaltungsberufsgenossenschaft (General Insurance in Professional Sports)

Declarations

Ethical approval: This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the University of Regensburg (no. 15-101-0134).

Consent for publication: Not applicable.

Availability of data and materials: The datasets used and analysed during the current study are available from the corresponding author on reasonable request, except insurance data which is property of the insurance itself.

Competing interests: None.

Authors' contributions: JW and WK writing, conceptualization, AE and WK and JW analysis, DP, VA, MN and CR acquisition and interpretation of data, substantial revision.

Funding: The authors have no relevant financial or non-financial interests to disclose.

Informed consent: Not necessary, as study was performed on video material in which no patient-specific data was obtained.

Acknowledgement: Special thanks to the Bavarian Football Association (Bayerischer Fußball Verband, BFV) for providing video material of the fourth German football league. Additionally, we want to thank Christian Klein, Patrick Luig and Hendrik Bloch from the German Public Trauma Insurance for Elite Athletes (VBG) for the exchange and support in preparing the detailed and sport-specific study protocol for video analysis. Many thanks also to the Centre of Clinical Studies at the University Medical Centre Regensburg.

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Figures

Heading questionnaire

- O) **Position:** ① goal keeper ② centre back ③ l/r back ④ defender (n.d.) ⑤ defensive mid-fielder ⑥ offensive mid-fielder ⑦ mid-fielder (n.d.) ⑧ striker
- Q) **Situation:** ① offense ② defense
- R) **Foul:** ① player ② opponent
- S) ① head below the pelvic area

Match day:

Date:

Match:

Number of header:

Minute of the match:

Number of player:

Number of injury

- A) **Score:** ① behind ② draw ③ in front
- B) **Action:** ① no duel (distance of more than 2 m) ② duel
- C) **Body contact:** ① no ② yes
- D) **Area of body contact:** a) player: ① head ② arm ③ trunk ④ leg ⑤ foot
b) opponent player: ① head ② arm ③ trunk ④ leg ⑤ foot
c) team member: ① head ② arm ③ trunk ④ leg ⑤ foot
- E) **Situation:** ① ball from team member ② ball from opponent player
- F) **Type of ball:** ① corner ② goal kick ③ high pass/ball ④ header ⑤ throw-in ⑥ free kick ⑦ cross ⑧ ground ball
- G) **Flight distance of ball:** ① very short (< 5 m) ② short (5 – 15 m) ③ medium (15 – 30 m) ④ long (> 30 m)
- H) **Angle of ball:** ① <0° ② 0°- 40° ③ 40°- 90°
- I) **Type of heading:** ① active header ② sliding ball ③ return pass ④ diving header ⑤ pick-up of or running with ball ⑥ no ball contact ⑦ unintentional head impact
- J) **Affected head area:** ① frontal ② temporal ③ parietal ④ occipital
- K) **Elbow position:** a) player: ① below shoulder-height ② at shoulder-height ③ above shoulder-height ④ face
b) opponent player: ① below shoulder-height ② at shoulder-height ③ above shoulder-height ④ face
- L) **Jump:** a) player: ① no jump ② while moving ③ using run-up speed ④ while running
b) opponent player: ① no jump ② while moving ③ using run-up speed ④ while running
- M) **Jumping height:** ① same height ② higher jump of player ③ higher jump of opponent player
- N) **Movement:** ① none ② to the ball ③ away from the ball ④ to the side
- P) **Localisation of player:** ① in front of opponent player ② behind opponent player ③ next to opponent player

Figure 1

Heading protocol for analysing heading situations in football

Figure 2

Heading frequency in football field areas

Figure 3

Heading (above) and critical incident frequency (below) in playing positions