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Video analysis of heading and risk of head injury situations in elite international men's football: Does the frequency of headers increase with the level of play?

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Abstract

Football is the only sport in which the ball can be played with the head. Therefore, compared to other ball team sports, head injuries are quite common. Headers and head injuries are dreaded to cause severe neurological impairments in long-term, but there is still a lack of data on how often headers are performed in different levels and how often head injuries occur. In a prospective cohort study, all heading situations as well as incidents with a propensity of injury (critical incidents) of 45 elite-level international matches were analyzed using a standardized video analysis protocol and compared to existing data from German professional leagues. A total of 3670 headers were recorded in 4050 match minutes (0.9 headers/minute). A mean of 81.5 headers per game (SD = 18.4) and 3.7 headers per player and match (SD = 0.8) was found. Compared to a cohort group of the German Bundesliga and 2nd Bundesliga, a significant reduction of −33.8 headers per game ($p < 0.01$) and 1.7 per player and match was found. A total of 18 risk of injury situations were recorded giving a rate per match of 0.4 (SD = 0.6). In comparison to the German league data, this also displayed a reduction. The incidence rate was 266 risk of injury situations per 1000 h match exposure, which was far below the rates of German national data (314/1000 h) and correlated with the frequency of headers performed.

KEYWORDS
football, head injury, header, heading, soccer, video analysis

Highlights

- This study found a significant reduction of frequency of headers with an increasing level of play. The number of acute head injuries correlated with the number of headers.
- Furthermore, central defenders had to perform the most headers, and therefore, they were exposed to a higher risk of suffering a head injury. Most headers appeared in defensive situations, and the penalty areas were found to be the most dangerous spots on the field.

- The frequency of headers found was far below the data in the existing literature. The results enable further experimental studies to be adapted to real match situations. The risk factors identified in this study provide an incentive for prevention such as stricter rule interpretation.

1 | INTRODUCTION

Football is the most popular sport in the world with over 270 million players worldwide and 62 million in Europe (Kunz, 2007). Playing the ball with the head is unique in football because it is not allowed in any other ball sport (Forbes et al., 2016).

In the past years, heading in football got more and more criticized and scientific interest on neurological effects has increased (Kirkendall et al., 2001; Stephens et al., 2010). Especially long-term neuro-psychological and structural changes are reasons to worry (Koerte et al., 2012; Mackay et al., 2019; Matser et al., 1999), although a recent meta-analysis did not reveal any causal links between hitting the ball with the head while playing football and long-term neuropathological impairments (Kontos et al., 2017). Risk of injury situations are mostly assumed to occur not by hitting the ball with the head but by collisions with other players or the ground (Andersen et al., 2004; Beaudouin et al., 2017). Video analysis is an approach on how to correctly identify the heading burden per player and match and risk of injury situations under real-life conditions. First data from Weber et al. of German professional male football showed a lower heading burden than estimated in the existing literature (Putukian et al., 2000, p. 107; Straume-Naesheim et al., 2005; Weber, Reinsberger, et al., 2022).

The aim of the study was to analyze international elite male football on behalf of heading and risk of injury situations in order to close the gap of missing epidemiological data of video analysis and to compare the existing data to German professional men's football.

2 | MATERIALS AND METHODS

In a prospective cohort study, 45 international football matches with German participation were analyzed using video analysis by using existing questionnaires (Weber, Ernstberger, et al., 2022; Weber, Reinsberger, et al., 2022) and compared to a data set of the German Bundesliga and 2nd Bundesliga. Video material included matches from FIFA World Cup (n = 3), UEFA European Championship qualifiers (n = 8), UEFA Nations League (n = 4), UEFA Champions League (n = 15), and UEFA Europe League (n = 15). The hypothesis of the study was that the frequency of headers decreased with increasing level of play, and the amount of head injuries depended on the heading numbers. Since there is no consequent definition of "elite" in the existing literature, the UEFA Club Coefficient was used to classify the cohort group (Waldén et al., 2023). The teams that were observed in our study were at the top of this ranking during the observed period (Union des Associations Européennes de Football). In addition, only the best players of a country are selected for their national teams, which is why we classified them as "elite".

Video material was provided by public TV broadcasters, and therefore, the visual quality was at a very high standard (HD), which made a detailed analysis easier. Every touch of the ball with the head was determined to count as a header. Risk of injury situations were defined as critical incidents (CI) by using the model of Andersen et al., which was further developed by Bjørneboe et al. (2014). After the model of Andersen, a CI occurs when a player gets hit on the head and the referee interrupts the match or if one player involved in the tackling was obviously in pain and lying on the pitch for more than 15 s or had to be carted off the field (Andersen et al., 2004, p. 691). Each heading situation and each risk of injury situation were inserted in an online-based database REDCap (Vanderbulit University) by using a standardized protocol. The protocol for headers contained 18 items to precisely describe the circumstances of the header. In addition to general information, such as game minutes and player position, it also included field position, flight distance and angle of the ball, impact area of the ball on the head, tackling situation, and elbow height for the heading player and his opponent. Another protocol was used especially for risk of injury situations and contained 27 items to describe background, the situation itself, and risk factors. It included player and field position, affected areas on the head, and other body regions and mechanism. Furthermore, the consequences of the risk of injury situation and the referee's decision were recorded. For a more accurate interpretation, each header or risk of injury situation was viewed several times and in slow motion according to a standardized scheme. Answering the protocol was mainly accomplished by L. H. and J.W. Unclear situations were evaluated by multiple observers and rated by consensus. Before the study was carried out, more than 150 heading and 20 risk of injury situations were assessed in a team of 4 observers in order to ensure a high inter-observer reliability. Because of the different proportions and camera positions in the stadiums, the distances were estimated as precisely as possible using field lines and standardized dimensions of a football field.

Descriptive data, such as characteristics of headers and head injuries, are described in absolute numbers and percentages. Odds ratios were calculated with confidence intervals of 95%. A p-value of <0.01 was considered as statistically significant. The statistical analysis of the questionnaires was carried out by using IBM SPSS Statistics 25 (International Business Machines Corp.).

The study design was approved by the Ethics Committee of the University of Regensburg (No. 18-846-101).

3 | RESULTS

In 45 international games and 4050 match minutes, 3670 headers were analyzed. By this, an average number of 81.5 headers per game (SD = 18.4) and 0.9 per match minute (see Table 1) could be detected. We also analyzed 68 games of the German Bundesliga and 2nd Bundesliga (season 2017/18), which resulted in an average heading frequency of 115.3 (SD = 25.3). In comparison with the German national data, there is a significant reduction of −33.8 headers per game ($p < 0.01$) in the international cohort group (compare Figure 1).

The mean heading rate per player and game was 3.7 (SD = 0.8), which meant a reduction of −1.5 headers per player (5.2 headers/player and game in the national data, SD = 1.2). In both groups, central defenders performed most of the headers in a team (34.6%) and all defenders together more than half (55.4%). Goalkeepers also carried out headers, but their heading rate was low (0.2%). With regard to field positions, most headers occurred in central midfield (48.1%) followed by the penalty areas (27.3%). Most of the headers were performed after high passes (37.3%), previous headers (17.8%), and goal kicks (17.6%). 64.6% were recorded in defensive playing situations, which means that the heading player had a defensive intent while performing the header regardless of his position. The most-detected flight distance of the ball was 20–50 m (49.8%). Most of the time, players headed the ball with high impact to the head and a change of flight direction of more than 90° (70.8%). For this, they usually used their frontal head area (72.3%). 55.3% of all headers occurred during tackling, and in 75.8%, there was physical contact with at least one other player. In 16.4% of all cases, the heading-performing player positioned his elbow at shoulder height or higher compared to 11.3% of the opponent player. This rate was even higher in the German leagues' data where the heading-performing player held his elbow in 25.4% of all tackling situations at shoulder height or higher and the opponent player in 18.8%. The referees rated 4.4% of all headers as a foul (see Table 2).

TABLE 1 Frequency of headers and risk of head injury situations in international football.

Matches	45
Match minutes	4050
Total headers	3670
Headers per match	81.5 (±18.4)
Min.	54
Max.	123
Headers per match minute	0.9
Headers per player and match	3.7 (±0.8)
Head injury situations	18
Head injury situations per match	0.4 (±0.6)
Head injury situations per player and match	0.02 (±0.03)
Incidence rate per player per 1000 h match exposure	12.1
Incidence rate per 1000 headers	4.9

In 45 games, 18 risk of head injury situations were detected (rate per match 0.40, SD = 0.6). The overall incidence rate of CI per player and match was 0.02 (SD = 0.03) and 12.1 per player and 1000 h match exposure (see Table 1). Compared to the German national data, this also means a reduction (rate per match 0.47, incident rate per player per 1000 h match exposure 14.3, see figure 1).

The players most affected were the central defenders (33.3%), whereas only one injury situation was recorded for goalkeepers. The area with the highest rate of critical incidents was midfield (50.0%) followed by the penalty areas (33.3%, compare Table A1). Although there were more critical incidents in the penalty areas in German national data than in the international cohort group, there was no statistically significant difference. 66.7% ($n = 12$) of the risk of injury situations occurred during headers, and 6 (33.3%) did not occur in context of heading situations. Of these, 3 included falls with subsequent impact, 2 were caused by a hit of the opponent during a running duel, and 1 by a collision while tackling on the ground. 77.8% of the CI occurred during aerial tackling situations (odds ratio: 2.8),

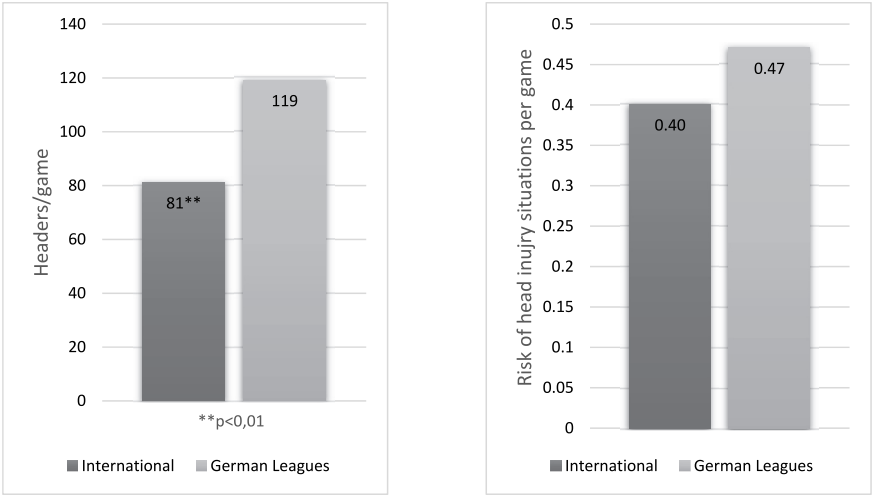

FIGURE 1 Heading frequency and CI rates in international and German league football (Bundesliga and 2nd Bundesliga).

TABLE 2 Characteristics of headers in international football.

Total number of headers	3670
Field area	
- midfield	1765 (48.1%)
- outer lane	903 (24.6%)
- penalty area	1002 (27.3%)
Match score	
- draw	1926 (52.5%)
- own team leading	912 (24.9%)
- opponent team leading	832 (22.7%)
Playing situation	
- free play	2410 (65.7%)
- free kick	218 (5.9%)
- goal kick	647 (17.6%)
- corner	227 (6.2%)
- throw-in	168 (4.6%)
Offensive/Defensive	1301 (35.4%)/2369 (64.6%)
Player position	
- goalkeeper	8 (0.2%)
- central defender	1269 (34.6%)
- full-back	764 (20.8%)
- defensive midfielder	644 (17.5%)
- offensive midfielder	574 (15.6%)
- forward	411 (11.2%)
Flying distance ball	
- <5 m	188 (5.1%)
- 5–20 m	942 (25.7%)
- 20–50 m	1829 (49.8%)
- >50 m	711 (19.4%)
Type of heading	
- passing	1530 (41.7%)
- clearing	1531 (41.7%)
- sliding ball	292 (8.0%)
- goal shot	190 (5.2%)
- picking up the ball	95 (2.6%)
- diving header	1 (0.1%)
- unintentional head hit	31 (0.8%)
Affected head area	
- frontal	2653 (72.3%)
- parietal	830 (22.6%)
- temporal	137 (3.7%)
- occipital	44 (1.2%)
- facial	6 (0.2%)
Heading duel yes/no	2028 (55.3%)/1642 (44.7%)
Body contact	
- contact with opponent	1468 (72.4%)
- contact w. player own team	11 (0.5%)
- contact w. more than 1 player	59 (2.9%)
- no contact	490 (24.2%)
Elbow height player	
- below shoulder height	1695 (83.6%)
- on or above shoulder height	333 (16.4%)
Elbow height opponent	
- below shoulder height	1798 (88.7%)
- on or above shoulder height	230 (11.3%)

while 83.3% involved body contact (odds ratio: 6.9). 77.8% of the injuries are caused by a collision with an opponent player or being kicked or hit. The most injured head area is the frontal region, which is affected in 83.3% of all injury situations, followed by the face (61.1%), the temporoparietal region (22.2%), and the occiput (16.7%). 33.3% of the injury situations were rated as a foul, and 16.7% were penalized with a yellow card (see Table A1).

4 | DISCUSSION

This study is the first to compare headers and head injury situations of German professional football players in national and international football. It provides new knowledge about the epidemiology of heading and head injuries in different playing levels. The average number of headers per game and player was 3.7, which is significantly less than assumed in the existing literature (Putukian et al., 2000; Rieder & Jansen, 2011; Straume-Naesheim et al., 2005). Previously existing interventional studies attempted to represent real match situations as best as possible, but the frequency and intensity of headers assumed were too high (Di Virgilio et al., 2016; Jansen & Lehmann, 2018). These numbers could therefore have influenced the results of these studies.

Comparing the frequencies found in international football to data of the German national leagues, there is a statistically highly significant reduction of over 30 headers per game. By comparing the English Premier League and the English Championship, Tierney and Higgins were also able to show that the number of headers decreased with increasing level of play (Tierney & Higgins, 2021). This was also shown by Weber et al. who compared the heading frequencies of the German Bundesliga to those of the 2nd Bundesliga (Weber, Reinsberger, et al., 2022). We assumed that national teams, and teams which take part in international competitions, perform at a higher level of play, and we also concluded that the heading frequency decreased with increasing level of play. This can be explained by the fact that the

players' technical skills are higher at the international level and that high balls are becoming less and less part of the modern game.

Center-backs had the highest heading exposure, which coincides with previous studies (Krutsch et al., 2018). Most headers were performed in defensive situations and in the defensive half of the field. This finding leads to the fact that heading in defensive situations should be exercised more frequently for injury prevention.

The rate of critical incident situations per 1000 headers did not significantly vary from international to German league football (4.9 vs. 4.1, see Table 1), but it appeared to be quite high compared to the national accident insurance registry (VBG, 2018).

In our investigation—although there is a limited level of comparability of injuries and risk of injury situations—only 3 risk of injury situations have been caused by a collision with the ball, whereas most risk of injury situations happen during direct physical contact with an opponent or a teammate. Matching with this low level of risk of injury situations caused by the ball, Delaney et al. could not attribute a single out of 39 concussions to the ball (Delaney et al., 2006).

In German national soccer, most headers were recorded in the midfield zones between the penalty areas, which was also evident in the international collective. This does not seem surprising as these areas occupy the largest area of the pitch. Nevertheless, in national comparison, most injury situations happened in the penalty areas, where there is a competitive fight for the ball. Compared to the international games, most critical incidents were registered in the midfield. However, the overall low frequency of injury situations may have influenced these results (Weber, Reinsberger, et al., 2022).

Although studies about heading, its frequency and characteristics have already been published in recent years, this work can characterize the headers and the risk of injury situations even more precisely with the questionnaires used (Tierney & Higgins, 2021). This comprehensive observation of heading made it possible to clearly present risk factors for head injuries and options for prevention. Concerning elbow positioning, professional football showed high positioning in almost 20% at shoulder height or even higher, even though intentional elbow hits are penalized with a red card. After this rule change, Beaudouin et al. were able to show statistically lower head injury rates (Beaudouin et al., 2017). Therefore, a special focus on elbow positioning should be applied and taught to referees. In order to perform headers safely, youth players should receive specific and safe practice for headers. With the FIFA 11+, a very successful warm-up program has been created, which has been proven to reduce the risk of injuries of the lower extremity. Now, there is a need to include heading exercises to this program (Jones, 2014). It is also important that players as well as backyard personnel know more about the symptoms and possible consequences of a concussion or head injury. Better educated players are more likely to stop physical activity at an appropriate time than noneducated players (Kurowski et al., 2015). Nevertheless, a large number of them return to competition after 1 week (O'Connor et al., 2017). These findings suggest that there are other incentives to resume play despite the knowledge of its dangerousness.

As other studies have already shown, video analysis has become a promising way of discovering and analyzing injuries in sports. This type of data collection is already used in various sports, such as Australian football (Makdissi & Davis, 2016) and rugby (Tucker et al., 2017). Although video analysis is not able to detect severe head injuries, such as concussions in absolute numbers, the use of it displays a useful tool in identifying risk situations or as supplemental tool for sideline testings or post-CI-surveillance of the affected player. For example, Cusimano et al. showed that if a player does not immediately continue playing after a head collision, he is likely to have two or more concussion symptoms in more than 80% of cases (Cusimano et al., 2017). The recordings used in this study were all made by professional television crews with cameras from several angles and at the highest visual quality. This and the standardized questionnaire that has been especially created for video analysis in football should guarantee a high level of objectivity in the evaluation.

One of the strengths of this study is the big sample of 3670 analyzed headers and the complete collection of 45 international games as this ensures analysis of realistic match situations. In addition, standardized questionnaires with predefined answer options were used to gain a high standard of inter and intraobserver objectivity, which have already proven their use and effectiveness in earlier studies.

However, this study also has some limitations. Only 18 risk of head injury situations were recorded in these 45 games, which may have influenced the evaluation of the data and their comparability. Furthermore, only 12 of the 18 injury situations actually occurred during heading situations. The rest included falls and collisions with other players besides heading duels. No follow-up was performed on the actual diagnoses and severity of the injury. In addition, there is a certain over-selection due to the use of critical incidents.

5 | CONCLUSION

This study provides epidemiological data of headers and head injuries in football during competition and shows how the frequency of headers performed changes when different playing levels are analyzed. In addition, differences in the characteristics of the headers could be shown. The average frequency of 3.7 headers per player and game was far below the numbers assumed in the existing literature. In addition, risk factors for a head injury, such as an elevated elbow position or contact with more than one other player, could be defined. With only 18 analyzed risk of head injury situations, their comparability is limited, and thus, there is an incentive for further research.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

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APPENDIX 1

TABLE A1 Characteristics of risk of head injury situations in international football.

Total number of CI	18
Field area	
- midfield	6 (33.3%)
- outer lane	2 (16.7%)
- penalty area	9 (50.0%)
Player position	
- goalkeeper	1 (5.6%)
- central defender	6 (33.3%)
- full-back	2 (11.1%)
- defensive midfielder	3 (16.7%)
- offensive midfielder	4 (22.2%)
- forward	2 (11.1%)
Playing situation	
- free play	16 (88.9%)
- standard	2 (11.1%)
Match minute	
- 1st half	10 (55.6%)
- 2nd half	8 (44.4%)
Action of the player	
- running	3 (16.7%)
- stopping	1 (5.6%)
- flight phase	8 (44.4%)
- landing	2 (11.1%)
- sliding	4 (22.2%)
Heading duel	
- yes	14 (77.8%)
- no	4 (22.2%)
Injured head area (multiple answers possible)	
- frontal	15 (83.3%)
- facial	11 (61.1%)
- temporoparietal	4 (22.2%)
- occipital	3 (16.7%)
Injury mechanism	
- collision with opponent	8 (44.4%)
- collision w. player own team	1 (5.6%)
- collision with ball	3 (16.7%)
- hit of opponent	3 (16.7%)
- kick of opponent	3 (16.7%)
Effect on player	
- able to leave field	13 (72.2%)
- carted off field	0
- stayed on field	5 (27.8%)
Time out	
- yes	15 (83.3%)
- no	3 (16.7%)
Substitution	
- yes	3 (16.7%)
- no	15 (83.3%)
Foul	
- no foul	12 (66.6%)
- foul heading player	1 (5.6%)
- foul opponent	5 (27.8%)