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Head Impact Situations in Professional Football (Soccer)

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ABSTRACT

To assess head impact incidents (HIIs) and to distinguish diagnosed head injuries from other incidents, a video observation analysis of match HIIs was conducted in the German Bundesliga (2017/18 season). Video recordings of each match were screened to identify the respective events. Head injury data were identified by a prospective injury registry. HII and head injury incidence rates (IR) were calculated with 95 % CIs. The total number of HIIs was 1362 corresponding to an IR of 134.9/1000 match hours (95 % CI 127.9–142.2). In 123 HII (IR 12.2, 95 % CI 10.2–14.5) the contact was classified as severe. Head contact with the opponent was the most frequent cause (85 %). The most frequent mechanism was in 44 % (combined) the arm and elbow-to-head, followed by head-to-head and hand-to-head contacts (each 13 %). In 58 %, the HIIs occurred during header duels. Twenty-nine head injuries were recorded (IR 2.9, 95 % CI 2.0–4.1). Concussions/traumatic brain injuries accounted for 48 %, head/facial fractures 24 %, head/facial contusions 21 %, and lacerations/abrasions 7 %. The number of HIIs not classified as concussions/more severe trauma was high. Identification of HIIs and head injury severity should be improved during on-field assessment as many head injuries might go unrecognised based on the large number of HIIs.

Introduction

Traumatic brain injuries (TBI) and particularly concussions in football have been the subject of increasing public discussions [1, 2]. The predominant focus of research has been on head injuries and headers. The incidence of head injuries has recently been examined and shown to be lower in football compared to other collision sports [3–5].

However, the number of unreported head injuries is unknown. It can be assumed that head injuries, especially concussions, are more frequent than reported [4, 6–10]. Undiagnosed concussions may be the result of being overlooked by non-medical professionals and/or medical staff due to mild symptoms and signs or even because of trivialized post-injury symptoms by the players themselves [8, 11–13]. As research has focused mainly on head injuries and headers being potential causes of brain damage and/or neurodegeneration in a cumulative manner, this narrowed perspective

potentially disregards head impacts that fall below the injury threshold and are not classified as headers. These head impact incidents (HIIs) may also play a role in terms of long-term sequelae. Previous research that used video observation detected incidence rates of approximately 33 and 53 %, respectively [14, 15]. Concerning was that most of the players did not receive an assessment for concussion, although showing signs of a head injury. This underpins the importance of this third category that needs more attention besides severe head injuries and headers.

Consequently, the number of HIIs with a biomechanical force transmitted to the head and brain or 'subconcussive blow', respectively, remains unclear. The severity of such HIIs cannot be estimated easily. It appears significant to shed light on the grey area between heading the ball and diagnosed concussions. Furthermore, head injuries have been trivialised in the past and field assessment by non-medical and medical professionals remains challenging.

The question remains, how frequently do head impact incidents occur in professional football and how many of these are identified as head injuries? Therefore, this study aims to assess the incidence of a third category of HIIs besides concussions (and more severe TBIs) and headers, by reviewing video material of all regular league matches of the 2017/18 season in German professional football.

Materials and Methods

Study sample and design

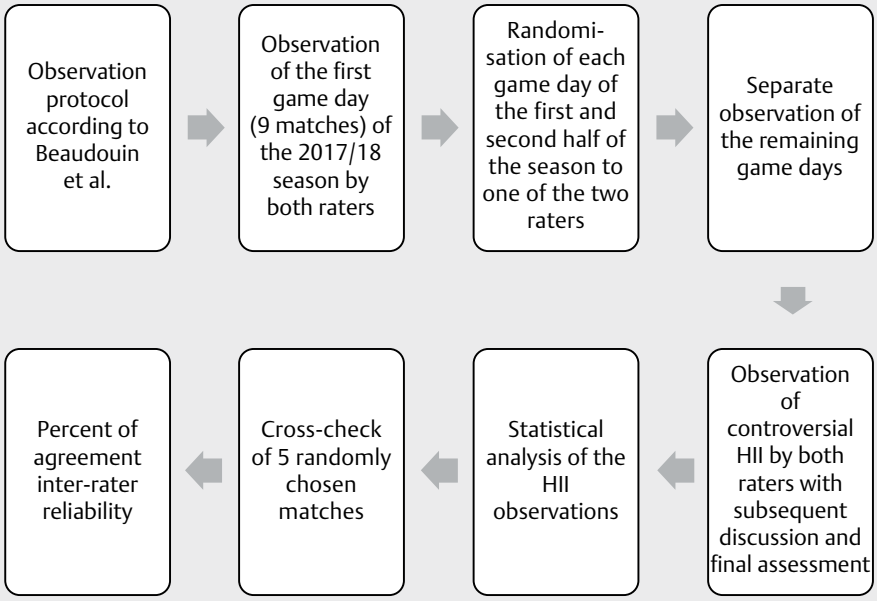
A retrospective video observation of matches from the first German league (Bundesliga) was conducted to determine the number of HIIs on players' heads across the 2017/18 season (306 matches). The video recordings were obtained from the Deutsche Fußball Liga (DFL; German Football League organisation). To estimate the number of concussions and more severe incidents, a standardized prospective analysis of match head injuries was conducted with a media-based approach as previously published [3, 4]. No approval from an ethics committee was required for this study [16] as all data were collected from public sources [3, 4].

Head impact incident assessment

An HII was defined as any external contact with a player's head (except regular heading) and consequently a visible biomechanical force transmitted to the brain. Each match of this season was screened to identify head injury-prone situations and the number of HIIs. The process of incident assessment is shown in ▶ **Fig. 1**. Two observers screened all matches during the 2017/18 season. The first game day weekend (9 matches, 18 teams) was observed together to become familiar with the demands of the investigation and to harmonize assessments. All remaining game days of the first and second half of the season were assigned to one of the observers in a randomised manner. A priori, a detailed observation protocol was developed on the basis of two recently published studies [4, 17] and is displayed in ▶ **Table 1**. Severe contact was classified through subjective evaluation. This assessment was conducted by multiple inspections with different camera/angle perspectives. Both raters jointly checked these identified incidents in order to classify them as 'severe'. The incident was finally classified being severe when both raters agreed on the following: 1) high-speed collision; 2) obvious visible head acceleration after the contact; 3) players being unaware of the imminent contact; and 4) players didn't continue playing/running immediately.

Head injury data collection

Head injury data collection followed an a priori defined protocol and analysis plan [4]. A prospective injury registry by national publicly available data was used. Data were mainly identified by a structured search in the 'kicker Sportmagazin' magazine (online edi-



▶ **Fig. 1** Process of head impact incident assessment.

▶ **Table 1** Observational items of head impact incidents.

Contact mechanisms between opponent/team mate	Hand-head, arm-head, elbow-head Shoulder-head, trunk-head, pelvis/hip-head Head-head Upper leg-head, knee-head, lower leg-head, foot-head Trunk-trunk, shoulder-trunk
Additional contact mechanisms	Ball-head, ground-head, goalpost/object-head
Player behaviour after HII	Player touches head Player falls to the ground Obvious pain Drowsiness No consequences
Player positions	Goal keeper Inside defender Outside defender Central midfielder Right and left wing Striker
Medical examinations by team physician/other medical personnel after the HII	Treatment No treatment No view due to camera position
Eligibility to continue playing	No substitution Substitution (immediate substitution or delayed substitution)
Head region of contact	Face Occipital, parietal, temporal, frontal Hyperextension cervical spine Unknown due to camera position
Severe impact on the head Duel type	yes no Header/aerial duel Duel on the ground
HII, head impact incident.	

tion). This magazine offers publicly available injury information. It provides data on diagnosis and time loss of each (head) injury. The magazine is published twice weekly with one journalist being responsible for one club and having contact with the press office of the clubs on a daily basis (in addition to players, coaches and staff members). Injury reports and summaries of each official league match are published. The online version also offers the opportunity for a free text search. Additionally, web pages (transfermarkt.de, ligainsider.de), social media of the players/teams (Twitter, Facebook, Instagram), team homepages and newsletters, TV sports channels, and local news were screened.

The subcategory 'suspected concussion' (independent from the original injury) was created [3]. This term included fractures of the zygomatic bone and skull as well as head contusions (to the skull and zygomatic bone only).

The severity classification of injuries was based on the time loss according to the consensus statement from previous football injury research [18]: slight (0 days), minimal (1–3), mild (4–7), moderate (8–28), and severe (> 28).

Match exposure

Match exposure per team was calculated using the following calculation [18]: number of matches x number of players on the field (11) × duration of the match in hours (1.5 h per match).

The analysis included all 34 matches being played by each club in the regular season. Cup games, friendly, and national games were not analysed.

Inter-rater reliability

Inter-rater reliability was checked by each rater reviewing 5 matches of his counterpart. Criteria for this re-evaluation was if the same HII including player identification and time during the match was identified by the other reviewer. In 79 % of cases the incident was identified. 21 % showed a disagreement between reviewers. Reasons for disagreements were difficult match situations with no clear view whether contact occurred.

Statistics

All statistical analyses were performed using Microsoft Excel 2019. HII and head injury incidence rates (IR) were calculated: incidence = (number of injuries or HIIs / hours of match exposure) × 1000. 95 % confidence intervals (CIs) were calculated [19]:

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

For comparisons between head injuries and HIIs, incidence rate ratios (IRR) were calculated. Descriptive data are presented as absolute numbers, percentages in parentheses, mean, and standard deviations (SD).

Results

Match exposure and HIIs

306 matches were included with a match exposure of 10098 hours. The number of HIIs was 1362 (IR 134.9/1000 match hours, 95 % CI 127.9–142.2). Contact mechanisms of the HIIs are shown in ▶ **Table 2**. In 123 HIIs (IR 12.2, 95 % CI 10.2–14.5), the contact was classified as severe.

Head injuries

Twenty-nine head injuries were diagnosed (IR of 2.9/1000 match hours, 95 % CI 2.0–4.1). Concussions/TBIs accounted for 48 % (IR 1.4, 0.8–2.3), head/facial fractures 24 % (IR 0.7, 0.3–1.5), head/facial contusions 21 % (IR 0.6, 0.3–1.3), and lacerations/abrasions 7 % (IR 0.2, 0.1–0.8). The 29 head injuries are included in the total number of HII, i.e. they were all detected during video analysis. The subgroup 'suspected concussion' accounted for 17 % of all head injuries and included 4 head contusions and 1 fracture of the zygomatic bone. The IRR between HII and head injuries was 46.0 (95 % CI 31.8–66.4). Of the 1362 HIIs, 2.1 % were identified as head injuries.

The mean time loss was 8 ± 10 days (median 5 days, range 2–55 days). Nine head injuries were minimal, 10 mild, 9 moderate, and 1 severe. The highest time loss was observed in facial/head frac-

▶ **Table 2** Observation of head impact incidents

	n (%)	IR per 1000 match hours (95% CI)
Contact mechanism		
With opponent	1156 (85)	114.5 (108.1–121.3)
With team mate	57 (5)	5.6 (4.4–7.5)
Arm-to-head	327 (24)	32.4 (29.1–36.1)
Elbow-to-head	265 (20)	26.2 (23.3–29.6)
Head-to-head	171 (13)	16.9 (14.6–19.7)
Hand-to-head	170 (13)	16.8 (14.5–19.6)
Shoulder-to-head	109 (8)	11.0 (9.0–13.0)
Trunk-to-head	47 (4)	4.7 (3.5–6.2)
Foot-to-head	34 (2.5)	3.4 (2.4–4.7)
Pelvis/hip-to-head	16 (1)	1.6 (1.0–2.6)
Knee-to-head	16 (1)	1.6 (1.0–2.6)
Upper leg-to-head	14 (1)	1.4 (0.8–2.3)
Lower leg-to-head	6 (<1)	0.6 (0.3–1.3)
Trunk-to-trunk	33 (2.5)	3.3 (2.3–4.6)
Shoulder-to-trunk	15 (1)	1.5 (0.9–2.5)
Ball-to-head	78 (6)	7.7 (6.2–9.6)
Ground-to-head	59 (4)	5.8 (4.5–7.5)
Goalpost/object-to-head	0	0
Head region of contact		
Face	616 (45)	61.0 (56.4–66.0)
Occipital	312 (23)	30.9 (27.7–34.5)
Temporal	174 (13)	17.2 (14.9–20.0)
Parietal	130 (10)	12.9 (10.8–15.3)
Frontal	59 (4)	5.8 (4.5–7.5)
Hyperextension cervical spine	19 (1)	5.8 (4.5–7.5)
Unknown (camera position)	59 (4)	1.9 (1.2–3.0)
Duel type		
Header / aerial duel	783 (58)	77.5 (72.3–83.2)
Duel on the ground	447 (33)	44.3 (40.4–48.6)
Player behaviour after the HII		
Player falls to the ground	947 (70)	93.8 (88.0–100.0)
Player touches head	931 (68)	92.2 (86.5–98.3)
Obvious pain	498 (37)	49.3 (45.2–53.8)
Ataxia	150 (11)	14.9 (12.7–17.4)
No consequences	90 (7)	8.9 (7.3–11.0)
Medical examinations by team physician/other medical personnel		
Treatment	1212 (89)	120.0 (113.5–127.0)
No treatment	146 (11)	14.5 (12.3–17.0)
No view (camera position)	4 (<1)	0.4 (0.2–1.1)
Eligibility to continue playing		
No substitution	1326 (97)	129.7 (131.3–138.6)
Substitution	36 (3)	3.6 (2.6–4.9)
-Immediate substitution	19	1.9 (1.2–3.0)
-Delayed substitution	16	1.6 (1.0–2.6)
-Unclear timeframe	1	0.1 (0.0–0.7)
Player position		
Central midfielder	378 (28)	36.5 (33.0–40.5)
Striker	310 (23)	30.2 (27.0–33.8)
Inside defender	254 (19)	25.1 (22.2–28.3)
Right and left midfielder	222 (16)	21.7 (19.0–24.8)
Outside defender	183 (13)	17.4 (15.2–20.4)
Goal keeper	15 (1)	1.5 (0.9–2.5)

Multiple mentions possible. CI, confidence interval; HII, head impact incident; IR, injury incidence rate.

tures (16 ± 18 days, median 9 days, range 4–55), followed by lacerations/abrasions (9 ± 6, median 9, 4 and 13), concussions/TBIs (6 ± 5, median 5, range 2–20), and head contusions (6 ± 4, median 4, range 2–10).

Head injury mechanisms

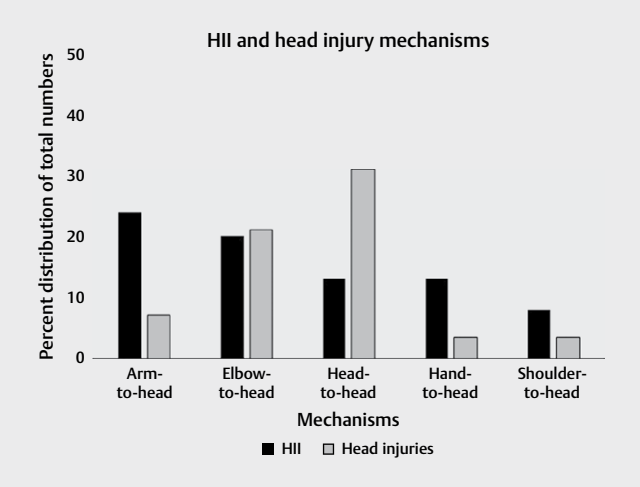
The most frequent head injury mechanism was head-to-head (31%, IR 0.9, 95% CI 0.5–1.7), followed by elbow-to-head (21%, IR 0.6, 95% CI 0.3–1.3) and shoulders-to-head (10%, IR 0.3, 95% CI 0.1–0.9). The comparison of the predominant HII and head injury mechanisms is shown in ▶ **Fig. 2**.

Discussion

The rationale of this study was to assess the research question of how frequently HIIs occur in professional football and how many of these are in fact identified as head injuries. Therefore, a third category of HIIs besides concussions (and more severe TBIs) and headers was characterized in order to shed light on the grey area between headers and head injuries. The most important finding of this study is the very high incidence rate (~135/1000 h) of head impact incidents in professional football of which only a few were diagnosed as head injuries (2.1%) according to the prospective injury registry. Secondarily, the underlying mechanisms were mainly arm and elbow-to-head and head-to-head contacts, which is similar to previous studies that described head injury mechanisms in football [3, 4]. The actual number of head injuries and the corresponding head IR were low compared to previously published data in professional football with head-to-head and elbow-to-head being the most frequent head injury mechanism. This study aimed to initiate a debate whether HIIs might be potentially relevant for the assessment of a "traumatic load" in players' brains because of their much higher frequency than concussions. Although this aspect was not within the scope of this study, it might become a relevant topic in near future.

Head injury data and mechanisms

Head injuries bear the risk of serious acute and long-term consequences [1, 2]. Long-term sequelae of head injuries and repetitive head impacts include post-concussion syndrome (PCS) or – if they occur repetitively – chronic neurocognitive impairments (e.g. mild cognitive impairment (MCI)) or even chronic traumatic encephalopathy (CTE) [1, 2, 20]. Previous research has linked exposure to repetitive head impacts to potential long-term neurological sequelae [21–23]. Initially, head injury research predominantly focused on high-risk sports such as American football, rugby, boxing, or ice



▶ **Fig. 2** Five predominant head impact incident and head injury mechanisms.

hockey. However, head injury rates in football have also received some attention in recent years, despite the lower collision and contact rates in comparison to the aforementioned sports [1, 2]. The IRs of head injuries in this study (2.88) were low compared to the high-risk sports [5, 24–26]. Compared to other football studies, however, the present IRs were slightly higher. Match IRs ranging from 0.70–2.22 per 1000 match hours have been reported in recent years [3, 4, 7, 27–31]. The main reason for the higher numbers in this database is probably the unique data collection approach, which is less dependent on the willingness of the medical staff to provide reports, which has potentially decreased under the growing media attention particularly for the concussion issue. The highest rates of head injuries were previously reported during FIFA World Cup tournaments (12.5 and 11.3) [32, 33]. It appears that it is rather difficult to compare head injury data from international tournaments with head injury data from regular league activity. The importance and the intensity of tournaments' matches are usually very high, which might suggest a more aggressive playing style resulting in an increase of all injuries including head injuries.

The head injuries in this study were most frequently caused by head-to-head (31 %) and elbow-to-head (21 %) contacts, which agrees with previous reports [3, 4]. Head-to-head was previously considered to be the predominant injury mechanism with regard to the causation of head injuries [3, 4, 7, 34]. With a view toward head injury prevention, diminishing this injury mechanism is undoubtedly an important step in the near future. In 2006, the International Football Association Board changed the rules of the game and decided that direct and deliberate elbow-to-head blows have to be punished with a red card. This rule change has led to a reduction of these contacts by 23 % as shown in a previous study [3]. A reduced number of elbow-to-head contacts was also described by another study after stricter interpretation of the rules [28]. Nevertheless, it appears to be impossible to completely prevent this injury mechanism because match dynamics, movement speed, applied techniques, equipment, and game play in general (e.g. tactics) seem to show a continuous evolution with increased physical and technical demands of the game [35–37].

Head impact incidents and mechanisms

The present analysis focused on a third category of HIIs besides concussions (and more severe TBIs) and headers and revealed a high number of HIIs during league matches. When match exposure is considered, the IR reaches ~135 per 1000 match hours. Such HIIs may be considered "sub-concussive" blows; this term describes a cranial impact with potential neuronal changes similar to those in concussion but without the symptoms of a concussion [22]. HIIs have been less in focus than head injuries and headers, especially in terms of long-term sequelae [38], although this third category might be relevant for an assessment of the "traumatic load" in players' brains. Two previously published video observation reports of head collision events during the FIFA World Cup 2014 and 2018 detected an IR of approximately 33 and 53, respectively [14, 15]. In over 60 % of the incidents, the players did not receive an assessment for concussion following an established protocol, although they showed signs of a head injury according to the authors' standardized assessment. It is likely that the real number of head injuries is higher than previously reported as some injuries might remain unreported, particularly concussions [8–10]. Their signs and symptoms can rapidly change as well as disappear [20]. This injury category is considered to be one of the most complex acute ones to diagnose, assess, and manage [20]. For the present analysis, it appears impossible to determine how many HIIs were in fact undiagnosed head injuries. At least 9 % of all HIIs were classified as severe, of which 43 % received medical treatment, but only 7 % were diagnosed as head injuries according to the media-based information. Although rather speculative, if only these severe HIIs had been undiagnosed as head injuries, it would make this injury location one of the most frequently affected body parts compared to other injury locations [6, 39, 40].

Head contact with the opponent or team mate was apparent in 85 % of all HIIs. As all HIIs are generally contact-related, there was a biomechanical force transmitted directly to the head, which is part of the general concussion definition [1, 41]. The most frequent mechanism was the arm and elbow (combined), followed by head-to-head and hand-to-head contacts. A header duel was apparent in most of all HIIs. These trends are compatible with studies determining the head and elbow as well as header duels as the most frequent head injury mechanisms and causes [3, 4, 7, 34]. In most HIIs the player showed signs of at least a minor head injury when considering the large number of players that required a medical examination by the team physician or other medical personnel or touched their head after the incident in obvious pain. As a matter of fact, in 97 % of the HIIs, affected players were not substituted, giving rise to the assumption of some unrecognised head injuries. Of the HIIs classified as severe, merely 16 % were substituted. Additionally, contact locations on the players' heads are potentially important for head injuries. Temporal, occipital, or parietal contact on the head are likely signs for an unexpected contact with the opponent, etc., and such scenarios likely limit the preparedness of players for the incoming impact with the consequence of more damage [17].

The present analysis may strengthen further in-depth discussions within the medical and scientific community about the management of this newly defined category of HIIs and, accordingly, head injuries. Equally important as reducing the number of head

injuries is improving the accuracy in diagnosing and managing TBIs. Although injury-preventing rules have been introduced (for instance, a red card for elbow-to-head contacts and FIFA's concussion rule with a 3-minute break), there are still debates around the implementation of a more extensive 'concussion safety protocol'.

Methodological considerations

Ideally, the video recordings should provide various perspectives, slow motion, and display high-resolution quality, which was not available for all scenes. Throughout the analysis, difficult HIIs were discussed and a final assessment made. Matches other than regular league matches and training sessions were not included and this can be regarded as a limitation of this study. Relying solely on video reviews of all matches without having access to actual injury reports is arguable, but access to injury reports of the teams is somewhat impossible. Teams do not intend to share sensitive data with the media. However, the underlying methodological standards (media-based injury registries) have previously been used in injury research [3, 4, 42–44]. The advantage is the massive increase in availability of media-based information [6, 7, 28, 45, 46]. Especially, head injuries have received increased attention in football in recent years. In particular, concussions were subject of public discussions described by media sources. The present media-based data were not validated with medical records by each team's medical departments, which are typically considered the gold standard [6, 28, 32, 33, 47]. But even for reports from the medical staff there is no guarantee of data integrity as a recently published study found that medical staff reports underestimated the incidence of time-loss injuries by up to 20 % [46].

The level of investigation and depth of media coverage allows for adequate data collection and therefore, the present analysis is considered to be fairly complete. Nevertheless, these injury data were extracted from non-medical publications and their accuracy should be interpreted with some caution.

This analysis attempted to shed some light on the discussion of unreported head impacts, but it cannot precisely quantify how many of the HIIs may in fact be undiagnosed head injuries. Wearable sensor systems or high-resolution video (e.g. calculating peak linear accelerations) can help to identify the severity of HIIs and the impacts on the brain in future [48]. However, regarding the biomechanical forces to the head due to contacts with the opponents or team mates (in some rare cases the ball), it can be assumed that a considerable number of them has been a head injury.

We used the diagnosis 'suspected concussion' in the case of certain traumas as substantial force is required to cause a facial fracture, and this can well be associated with an intracranial injury [49, 50]. 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.

Conclusions

The number of HIIs is high when including a third category besides headers and head injuries. The present results add valuable information as head injuries and other head impacts may be potential causes of cumulative brain damage and/or neurodegeneration. The identification of HIIs and additionally head injury severity should be improved during on-field assessment as many (potential) head injuries might go unrecognized based on the large number of HIIs. For clinical practice, head impacts bear the risk of short- and long-term health sequelae, the awareness of a considerable number of incidents apart from concussions and headers is important as the identification of head injury and head impact mechanisms is essential to develop preventative measures in the future.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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