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REVIEW

# Concussions and heading in soccer: A review of the evidence of incidence, mechanisms, biomarkers and neurocognitive outcomes

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## Abstract

*Background*: Soccer is currently the most popular and fastest-growing sport worldwide. Similar to many sports, soccer carries an inherent risk of injury, including concussion. Soccer is also unique in the use of 'heading'. The present paper provides a comprehensive review of the research examining the incidence, mechanisms, biomarkers of injury and neurocognitive outcomes of concussions and heading in soccer.
*Methods*: Seven databases were searched for articles from 1806 to 24 May 2013. Articles obtained by the electronic search were reviewed for relevance, with 229 selected for review. Ultimately, 49 articles met criteria for inclusion in the present review.
*Results*: Female soccer players have a higher incidence of concussions than males. The most frequent injury mechanism is player-to-player contact for both genders. Few studies examined the effects of concussion in soccer players; however, neurocognitive outcomes were similar to those reported in the larger sport concussion literature, while the effect of heading is less clear.
*Conclusion*: Despite variation in research designs and study characteristics, the outcomes of concussions in soccer align with the greater concussion literature. This review makes recommendations for future research to increase standardization of research for improved understanding of concussions in soccer as well as the effects of heading.

## Keywords

Brain injury, cognitive impairment, concussion, heading, repetitive head trauma, soccer, sport

## History

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**Abbreviations:** AB, Alphabet Backwards; AL, Associate Learning; AU, Alternate Uses; BFRT, Benton Facial Recognition Test; BTA, Brief Test of Attention; BTVM, Brief Test of Visual Memory; BVR, Benton Visual Retention; BWT, Bourdon-Weirsma Test; CCTT, Children's Color Trails Test; CFT, Complex Figure Test; COWAT, Controlled Oral Word Association Test; CRT, Complex Reaction Test; CVLT, California Verbal Learning Test; DS, Digit Span; DST, Digit Symbol Test; FDT, Figure Detection Test; FRT, Free Recall Test; FTT, Finger Tapping Test; HVLT, Hopkins' Verbal Learning Test; HWRT, Halstead-Wepman-Reitan Test; LFT, Letter Fluency Test; LM, Logical Memory; PASAT, Paced Auditory Serial Addition Test; PT, Puncture Test; RAVLT, Rey Auditory Verbal Learning Test; ROCFT, Rey-Osterrieth Complex Figure Test; RPM, Raven Progressive Matrices; SAT, Selective Attention Test; SCWT, Stroop Colour-Word Test; SDMT, Symbol Digit Modalities Test; SRT, Simple Reaction Test; ST, Stroop Test; TAP sub-tests, Tests of Attention Performance, includes divided attention, covert attention shift, flexibility and working memory; TMT, Trail-Making Test; TOL, Tower of London; VFT, Verbal Fluency Test; VLD, Verbal Learning Delay; VPA, Verbal Paired Associates; WDST, Wechsler Digit Span Test; WDSyT, Wechsler Digit Symbol Test; WMS, Wechsler Memory Scale; WRAML, Wide Range of Assessment Memory and Learning; 15WLT, 15-word learning test.

## Introduction

Concussions and other forms of mild traumatic brain injuries (mTBI) occur on average 1.75 million times a year in North America and account for ∼75% of all traumatic brain injuries (TBI) [1, 2], with the Centers for Disease Control (CDC) reporting ∼207 830 emergency department visits for sports-related TBIs per year between 2001–2005 [3]. Concussion, a type of TBI, is a clinical syndrome defined as a complex pathophysiological process, induced by traumatic biomechanical forces [4]. The CDC has recently declared that sport-related concussions are reaching 'epidemic levels' and deserve further research [1].

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Soccer is currently the most popular and fastest-growing sport worldwide, with over 265 million active players and ~27 million playing the sport within Canada and the US alone [5]. Due to the nature of the sport, soccer players are particularly vulnerable to various types of head and neck injuries, including lacerations, abrasions, contusions, fractures and concussions [6]. Most of the time, these types of injuries occur as a result of unintentional or unexpected contact, for example, when a player collides with teammates, opponents or the playing surface. The sport is also unique in its purposeful use of the head—referred to as 'heading'—a technique to advance or control the ball during gameplay.

Symptoms of concussion can be acutely debilitating, but typically resolve over time. Despite this, there is significant concern about the potential long-term cognitive and behavioural consequences for athletes with respect to acute concussion [7], repetitive concussions [8–11], as well as cumulative 'sub-concussive' head impacts, which are blows to the head not causing symptoms of concussion [12, 13]. While it is known that concussive injuries frequently result in a clinical constellation of symptoms, the practice of heading—which might occur thousands of times over a player's career—carries unknown risks; but heading may uniquely contribute to cognitive decline or impairment in the short- or long-term. Thus, soccer players present a unique opportunity to study whether cumulative sub-concussive impacts affect cognitive functioning, similar to that of concussion.

Increased understanding of and concern for concussions in all sports has resulted in the recent implementation of a number of strategies to help address the issue of concussions in sports. Such initiatives have included: education of players, coaches, athletic therapists/trainers and parents [14–16]; development of standardized assessment tools [17, 18]; consensus statements to provide guidelines for management [4, 19]; and legislation [15]. In addition, a number of sport organizations have implemented specific rules and policies—the National Hockey League (NHL) [20, 21], National Football League (NFL) [22], Hockey Canada [20, 23] and Soccer Shots Connecticut [24]—aimed to reduce the number of head injuries in their respective sports. Despite these actions, there are still a number of outstanding questions that have the potential to influence future prevention strategies. In particular for soccer, an understanding of the incidence and mechanisms of injury, the identification of risk factors and insight into neurocognitive outcomes could provide evidence for recommendations specific to possible rule changes, informing equipment manufacturers and contributing to management guidelines at all levels of play.

The goal of this review was to synthesize the literature to date to provide a comprehensive resource of the research examining concussion in soccer players. The specific aims of this paper were to: (1) systematically review studies investigating the incidence, mechanisms and acute neurocognitive outcomes of concussions in soccer; and (2) describe the evidence that has examined the short- and long-term neurocognitive effects of 'heading' resulting from soccer participation. This study then discusses the limitations of the current literature and suggests potential future directions to expand what is presently known about brain injury in soccer players.

## Methods

This review identified articles for inclusion primarily by searching electronic databases, in addition to reference lists of included papers. The following seven databases were searched: Ovid MEDLINE (1946 to week 3, May 2013), Embase (1980 to week 21, 2013), PyscINFO (1806 to week 3, May 2013), Web of Science (24 May 2013), Scopus (24 May 2013), SportDiscus (24 May 2013) and PubMed (24 May 2013). Searches were conducted in consultation with an institutional librarian using a combination of Medical Subject Headings (MeSH) and key words including: 'soccer', 'football', 'concussion', 'brain injur*', 'brain concussion', 'traumatic brain injur*', 'head injur*', 'tbi', 'cognit*', 'neurocognit*', 'neuropsych*', 'imaging', 'neuroimaging', 'mri', 'dti', 'ct', 'soccer heading', 'heading', 'header', 'biomarkers', 'serum biomarker', 's-100b', 'neuron-specific enolase' and 'NSE'. The terms pertaining to concussion were combined with the Boolean operator 'OR', as were the terms pertaining to cognition and those pertaining to imaging. Then these new groups of terms were put into different combinations with 'soccer' and/or 'soccer' and 'heading' with the Boolean operator 'AND' to yield papers on the topic of interest. Inclusion criteria were as follows: (1) Original data; (2) Study sample derived from a population of soccer players; (3) mTBI, concussion or head injury from soccer or heading; (4) Incidence, mechanisms and risk factors for concussion; (5) Imaging studies or neurocognitive studies of concussion and/or heading in soccer; and (6) Studies investigating biomarkers of brain injury. Exclusion criteria: (1) Non-English articles; (2) Review articles, commentaries, anecdotal reports, letters and case studies; (3) Multi-sport studies in which soccer-specific results could not be extracted; (4) Sample size less than five soccer players; (5) Studies evaluating effectiveness of various forms of concussion assessment tools or the effectiveness of headgear; (6) Studies evaluating biomechanical aspects of heading and/or soccer play or postural control after heading. A total of 2118 search results were yielded from all database searches; 229 of these were selected for full review after screening the title and abstract and, after removal of duplicates and screening out those that did not meet selection criteria, 47 papers were selected. An additional two studies were included from reviewing the references of these papers. Ultimately, 49 papers were included for review in the present study. The results of the database search are presented in Figure 1 and they are presented under each of their relevant sub-headings.

## Results

The studies included for review here are separated into four general themes addressing the incidence of concussions, mechanisms of injury, neurocognitive implications of concussions in soccer, as well as the potential consequences of heading. The section on heading in soccer is further divided into those studies investigating effects after short-term exposure, those looking at effects of long-term exposure

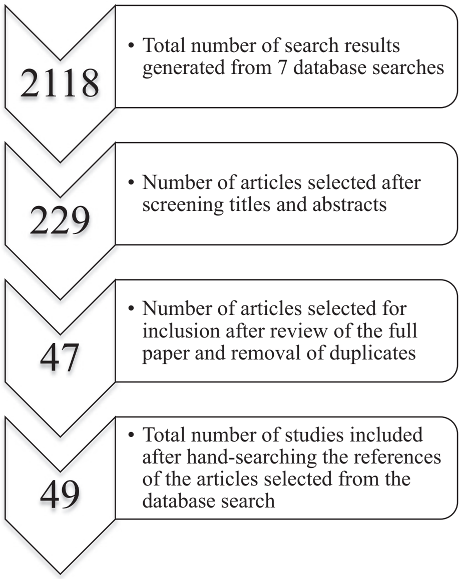


Figure 1. The results of the database search and literature review process.

and those investigating the presence of biomarkers of brain injury after heading exercises.

## Incidence of concussions in soccer

A total of 13 papers were selected according to inclusion criteria pertained to incidence. The results are summarized in Table I. These studies investigated the incidence rates in terms of 'Athletic Exposures' (AE), where one AE is considered a single practice or game. An epidemiological study of injuries in NCAA (National Collegiate Athletic Association) men's soccer over a 15-year period was conducted using data collected by the NCAA Injury Surveillance System (ISS) and, this study reported the incidence of concussions in terms of male players, to be 1.08 concussions per 1000AE [25]. Further analysis by this group of the NCAA ISS men's data showed that concussions accounted for 5.8% of total injuries sustained during games, with players being 13-times more likely to receive a concussion during a game than in practice. Dick et al. [26] then conducted a study focused on injuries sustained by female soccer players in the NCAA over the same time period, also using the ISS; this study reported an incidence rate of 1.42 per 1000AE. They determined that, in this population, concussions account for 8.6% of total injuries in soccer games and these athletes were up to 12-times more likely to sustain a concussion during a game than during a practice. Five studies evaluating concussion rates for female soccer players in high school reported similar frequencies, which varied from 0.23–0.36 per 1000AE [27–29]. Only one of seven studies comparing concussion frequency by sex indicated that males had a higher incidence [30]. It was also determined by this study that the overall incidence of concussions in soccer was 0.96 per team per season and that 69% of concussions occurred during games.

In a study of 201 Canadian varsity soccer players it was reported by Delaney et al. [31], based on the symptoms they

Table I. The incidence of concussions in various populations of soccer players.

| Paper | Sample | No of concussed athletes | Incidence in males | Incidence in females |
|---|---|---|---|---|
| Boden et al. [30] | 351 NCAA soccer players | 29 | 0.6 per 1000 AE in men | 0.4 per 1000 AE in women. |
| Powell and Barber-Foss [34] | High School soccer players | 76 Girls, 69 Boys | 0.18 per 1000 AE | 0.23 per 1000 AE |
| Delaney et al. [31] | Soccer players competing in the CIAU (CIS) | 126 | 62.27% of soccer players have suffered a concussions | |
| Covassin et al. [35] | Male & Female NCAA soccer players | 101 Males, 158 Females | 1.43 per AE over 3 seasons | 2.22 per 1000 AE over 3 seasons |
| Agel et al. [25] | Male NCAA soccer players | 387* | 1.08 per 1000 AE in games, 0.08 per 1000 AE in practice | n/a |
| Dick et al. [26] | Female NCAA soccer players | 463* | n/a | 1.42 per 1000 AE in games; 0.12 per 1000 AE in practice |
| Gessel et al. [29] | Male & female high school and collegiate soccer players | 183 | 0.22 per 1000 AE for high school athletes; 0.49 per 1000 AE in collegiate soccer players | 0.36 per 1000 AE in high school soccer players, 0.63 per 1000 in collegiate soccer players. |
| Rechel et al. [33] | Male & Female high school soccer players | ~53 Females**, ~36 Males** | 2.3% of practice injuries; 15.6% of competition injuries | 9.7% of practice injuries; 18.8% of competition injuries |
| Yard et al. [32] | Male & Female high school soccer players | Not reported | 9.3% of total injuries | 12.2% of total injuries |
| Giannotti et al. [40] | Youth soccer players aged 5–19 | 533 | 67.9% of concussions were seen in male soccer players | 32.1% of concussions were sustained by females |
| Lincoln et al. [28] | High School athletes | 195 Girls, 103 Boys | 0.17 per 1000 AE | 0.35 per 1000 AE |
| Castile et al. [36] | High school athletes | 181 Boys, 242 Girls | 0.197 per 1000 AE | 0.298 per 1000 AE |
| Marar et al. [27] | High school athletes | 262 | 0.19 per 1000AE | 0.34 per 1000 |

*Indicates that data were obtained from games only; **Indicates that the approximate number was calculated based on the total number of injuries and provided percentages in the study.

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experienced after a head impact, that 62.7% of soccer players have suffered a concussion during their playing careers, yet only 19.2% realized these symptoms constituted a concussion. It was also noted by the authors that 81.8% of the athletes who had suffered a concussion had experienced two or more concussions over the course of their playing careers and that players with a history of concussions had 3.15-times greater odds of sustaining a concussion during a given season compared to those who had never experienced a concussion. In a multi-sport study of high school athletes from 100 schools competing in 20 sports, concussions sustained during soccer play accounted for 15% of total concussions [27]. In particular, girls' soccer accounted for 8.2% of total concussions ($n = 159$), which was the second greatest number after football (47.1%, $n = 912$); boys' soccer ranked 5th overall in the same study (5.3%, $n = 103$). Similarly, Yard et al. [32] found that concussions accounted for 12.2% of injuries in female high school soccer players and 9.3% of male high school soccer injuries. This gender disparity in concussion incidence and proportion of injuries is corroborated by four other studies [33–36] and can be found in Table I.

## Mechanisms of injury

In terms of investigating the mechanisms of concussion in soccer players, 10 papers met inclusion criteria for review (see Table II for complete list). All of the studies identified player-to-player contact as the mechanism responsible for the greatest proportion of concussions in both male and female soccer athletes [25–27, 29, 30, 37–41]. Andersen et al. [37] examined 192 head injury incidents involving player-to-player contact and found that 79 (41.1%) concussions resulted from contact by an elbow, arm or hand to the head. With respect to the playing situation, 112 (58.3%) head injuries were sustained while the player was engaged in a heading duel. Similarly, Marar et al. [27] reported concussions accounted for 60% of all injuries sustained while heading the ball, while another study reported that the percentage was 64.1% [29]. More recently, Cusimano et al. [41] examined 2435 hospital emergency department visits in children aged 5–19 and 1211 (49.7%) were from player-to-player contact. Player-to-structure contact resulted in the second greatest number of brain injuries in this population, with 979 injuries (40.2%).

In two of these studies [27, 29], concussion mechanism was differentiated by sex and, while player-to-player contact was the leading cause of concussion in both males and females, a greater proportion of females sustained concussions from player-to-surface and player-to-ball contact compared to male players. In contrast, males sustained a greater proportion of concussions from player-to-player contact than females. It was suggested that sex differences in style of play and more aggressive play in males might account for this disparity.

Boden et al. [30] highlighted that concussions more often were a result of being struck in the head by balls kicked at close range, as opposed to the playing action of heading the ball. These results are supported by a biomechanical study by Hanlon and Bir [42], which showed that non-heading impacts from the ball resulted in greater head acceleration and subsequent head injury compared to impacts received from heading.

Player-to-surface injuries included players who fell and struck their head on the playing surface—which included the ground or the goalpost [25–27, 29, 30, 38, 40, 41, 43]. Other mechanisms included collisions with objects around the field of play such as fences, benches or bleachers [25, 26, 30, 40, 41].

## Player position

Player position appears to be an important factor in considering potential risk factors associated with concussion while playing soccer. Specifically, defensemen and goalkeepers are of greatest risk, sustaining more concussive injuries than forwards and midfielders (refer to Table III). A 2-year study of soccer players competing in the NCAA Atlantic Coast Conference found that 67% of female athletes who sustained a concussion were playing defense at the time of their injury [30]. Delaney et al. [31] conducted a study using medical history questionnaires completed by 201 soccer

Table II. Common mechanisms of concussive injury in soccer play.

| Paper | $n$ | Player-to-player | Player-to-surface | Player-to-ball | Other/combination of previous mechanisms |
|---|---|---|---|---|---|
| Barnes et al. [38] | 92 | 71.4% (females)<br>64.9% (males) | 17.9% (females)<br>14.9% (males) | 10.7% (females)<br>20.2% (males) | n/a |
| Boden et al. [30] | 29 | 48.3% | 17.2% | 24.1% | 10.3% |
| Andersen et al. [37] | 192 | Elbow/arm/hand in 79 cases (41%);<br>Head in 62 cases (32%);<br>Foot in 25 cases (13%) | n/a | n/a | n/a |
| Delaney et al. [43] | 18 | 66.7% | 22.2% | 1.1% | n/a |
| Agel et al. [25] | 387* | 80.60% | 8.00% | 8.00% | 3.40% |
| Dick et al. [26] | 463* | 67.70% | 14% | 18.30% | 0.60% |
| Gessel et al. [29] | 183 | 85.3% (boys);<br>58.3% (girls) | 6% (boys);<br>22.6% (girls) | 8.2% (boys);<br>18.3% (girls) | 64.1% of injuries sustained while heading the ball are concussions |
| Giannotti et al. [40] | 503 | 192 (38.1%) | 189 (37.6%) | 65 (12.9%) | 57 (11.3%) |
| Marar et al. [27] | 159 (girls);<br>103 (boys) | 76.7% boys and<br>52.8% girls | 7.8% boys and<br>18.2% girls | 15.5% boys and<br>26.4% girls | 60% of injuries sustained while heading the ball are concussions |
| Cusimano et al. [41] | 2435 | 49.7% | 40.2% | 7.4% | 2.7% |

*Indicates that data was collected from games only.

players competing in the 1998 Canadian Interuniversity Athletics Union season. They reported that 70.2% of defenders and 78.9% of goalkeepers had sustained a concussive head injury during the previous season. In a study assessing injuries sustained by both collegiate and high school athletes, it was determined that ~21.7% of all injuries sustained by soccer goalkeepers were concussions, while they represented only 11.1% of total injuries to soccer players in other positions [29].

## Impact of concussions on cognitive abilities

Four studies have employed neuropsychological screening batteries to assess soccer players' cognitive functioning and two have found that soccer players exhibit significant cognitive deficits following concussion [44, 45] (see Table IV for summary of studies). Using the ImPACT computer-based testing battery, Colvin et al. [45] found concussed soccer players ~9 days post-injury displayed significant impairments in memory, reaction time and visual-processing speed and impairments were more pronounced for females. Additionally, athletes who had previously experienced a concussion had significantly worse test scores for memory and visual-processing speed than those with a first concussion. Conversely, Zuckerman et al. [46] used the ImPACT test battery at baseline and within 10 days of injury and reported no statistically significant differences from baseline scores, as well as no significant differences between sexes after controlling for an array of biopsychosocial factors. It is important to note that, in both studies, female athletes reported significantly more concussion symptoms than male soccer players. Ellemberg

Table III. The risk of concussion associated with the position played. Boden et al. [30] had 29 concussed players and sorted the number of total concussed players into their position, while Delaney et al. [31] examined what proportion of players in a given position had experienced a concussion during their careers. Gessel et al. [29] evaluated what proportion of total injuries concussion represented in goalkeepers compared with all other positions.

| Paper | *n* | Goalkeeper | Defence | Midfielder | Forward | Unspecified |
|---|---|---|---|---|---|---|
| Boden et al. [30] | 29 | 6.90% of total concussions | 37.90% of total concussions | 27.60% of total concussions | 27.60% of total concussions | n/a |
| Delaney et al. [31] | 201 | 78.9% of Goalkeepers; 11.9% of total concussions | 70.2% of Defenders; 31.7% of total concussions | 57.7% of Midfielders; 32.5% of total concussions | 57.4% of Forwards; 21.4% of total concussions | 42.9% unknown; 2.4% of total concussions |
| Gessel et al. [29] | | 21.7% of total injuries | 11.1% of total injuries | n/a | | |

Table IV. Summary of studies that examined the effect of concussions on cognitive abilities.

| Paper | *n* | Objective | Population | Methods | Results |
|---|---|---|---|---|---|
| Guskiewicz et al. [47] | 240 | To determine whether long-term or chronic neuropsychological dysfunction is present in soccer players by comparing those with and without a history of concussions. | 91 soccer athletes, 96 non-soccer athletes, 53 non-athletes from an NCAA Division 1 school. | **TMT B, COWAT, SCWT, HVLT, SDM, WDST (forward and backward tests). | No significant results were seen when comparing the soccer players with and without a history of concussion. |
| Ellemberg et al. [44] | 22 | To investigate whether there are prolonged cognitive impairments after a concussion in female soccer players. | 22 female university soccer players—10 had previously sustained a concussion, 12 had never been concussed. | CVLT, Ruff 2 & 7 SAT, BTA, SDM, SCWT, ToL, LFT, Forward and Backward Digit Span, SRT, CRT. | Significant differences between the concussed and control groups were seen in 3 measures of processing speed—Stroop, TOL and CRT. |
| Colvin et al. [45] | 234 | To determine if soccer players with a history of concussion display deficits on neurocognitive testing and whether female soccer players are more severely impaired on these measures than males. | 234 soccer players: 141 females and 93 males. 101 athletes had a previous concussion, 133 had no previous concussion. | ImPACT Version 1.0—memory, reaction time and visual-motor processing. | Females displayed significantly poorer reaction time scores. Athletes with a prior history of concussions performed significantly worse in the memory component and the visual-processing composite score. |
| Zuckerman et al. [46] | 80 | To investigate gender differences in neurocognitive impairments between male and female soccer players. | 40 male and 40 female competitive soccer players sustaining a concussion during soccer play. | ImPACT 22-item Post-concussion Symptom Scale and ImPACT indices of verbal memory, visual memory, visual-motor (processing) speed, reaction time and impulse control. | Only the number of symptoms was significantly different between genders. |

**TMT B Full titles for all test abbreviations used are listed at the beginning of this paper.

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et al. [44] examined 22 female university-level soccer players at 6–8 months following their first medically diagnosed concussion. The authors reported chronic phase (months after the injury) impairments—specifically, concussed players exhibited significantly poorer executive functions compared with controls for tests of inhibition, planning and decision-making. Finally, a study by Guskiewicz et al. [47] examined soccer players pre-season ('baseline') neurocognitive performance scores and reported no significant differences in performance between (a) players with and without a history of concussions or (b) between soccer players and non-athlete populations.

## Effects of heading

### *Short-term exposure*

Seven studies are summarized in Table V and include those examining the effect of heading on cognitive functioning in athletes of 18 years and younger and also studies evaluating the effect of a recent bout of heading. Kontos et al. [48] investigated a group of youth soccer players and recorded the number of headers each player executed during two randomly selected games. However, they did not find any differences between low, moderate and high heading players on ImPACT scores. Similarly Janda et al. [49] followed youth soccer players (average age of 11.5) over 1 year (with a group of 18 boys ranging in age from 12.6–14.5 completing a 2nd year) and found no significant differences between players' pre-season and post-season cognitive testing scores. The authors concluded there was no cumulative effect of heading on neurocognitive performance. Putukian et al. [50] also investigated the acute effects of heading by conducting testing before and after two collegiate soccer practices—with the soccer players serving as their own controls—and found that there were no significant differences between baseline and post-heading test scores. In a study of 64 male soccer

Table V. A summary of the studies investigating the short-term effects of heading on neurocognitive performance.

| Study | *n* | Objectives | Sample | Testing methods | Results |
|---|---|---|---|---|---|
| Putukian et al. [50] | 100 | To prospectively examine the acute effects of heading in soccer on cognitive function. | Varsity soccer players from Penn State University and controls (21 male and 26 female) participated in this study for a total of 44 males and 56 females | AB, TMT A & B, SCWT and a modified VIGIL/W. | No significant performance differences were seen between soccer players and controls on the neurocognitive tests. |
| Janda et al. [49] | 61 | To evaluate the effect of repetitive head impacts due to heading in 57 youth soccer players with a mean age of 11.5 years. | 61 youth soccer players in Ann Arbor Michigan were monitored for 1 year. Data was collected for a team of 18 boys for one additional year. | WRAML, DS (forward & backward within the Wechsler Intelligence Scale for Children III), SDMT and VLD. | Year 1: No correlation was found between the number of times a child headed the ball and their cognitive testing scores. Year 2: A weak inverse association was seen between number of ball impacts and verbal learning. |
| Webbe and Ochs [51] | 84 | To investigate the role of heading recency interacting with heading frequency in determining neuropsychological deficits associated with heading the ball during soccer play. | 64 male soccer players from high school, college or professional teams in Florida. 20 male athletes with minimal experience in soccer, hockey, football and lacrosse served as controls. | CVLT, TMT A&B, Shipley (CQ), CVLT, ROCFT (copy), Shipley (IQ), ROCFT (Delayed Recall), FRT, PASAT. | Soccer players exhibited significantly poorer performance than controls on the CVLT, the PASAT and the Shipley IQ. Players with the highest heading estimates and who had played recently scored significantly lower on the CVLT Trial 5 and total scores, the Shipley CQ, TMT A&B and PASAT 2.4 trial. |
| Stephens et al. [52] | 23 | To determine whether heading affects neuropsychological test performance. | 23 male youth soccer players aged 13–16. | ROCFT, DS, DST, TMT, SCWT, LM, TAP subtests, WCST, AU. | Cumulative heading did not predict neuropsychological test scores with the exception of TAP divided attention ($r = -0.003$, $p = 0.018$). |
| Kaminski et al. [53] | 393 | To determine whether there is a relationship between heading in soccer and neuropsychological performance. | 393 female interscholastic (high school) soccer players from 16 difference high schools. Mean age: 15.8. | Automated Neuropsychological Assessment Metrics (ANAM). | There was no relationship between the number of headers a player performed in the season and performance on any of the ANAM subtests. |
| Stephens et al. [12] | 48 | To determine whether cumulative heading predicts neuropsychological testing performance in boys aged 13–16. | High school soccer players aged 13–16. | ROCFT, TMT, TAP, DS, DST, SCWT, LM, TAP sub-tests, WCST | Cumulative heading did not predict neuropsychological testing scores. |
| Kontos et al. [48] | 63 | To investigate the relationship between soccer heading & computerized neurocognitive performance & symptoms in youth soccer players. | 63 youth soccer players (27F & 36M) from competitive soccer teams ranging in age from 13–18 attending academically selective private schools. 9 males and 3 females reported a previous concussion. | ImPACT computerized neurocognitive testing battery version 2.0 | No significant differences were seen between the low, medium and high heading exposure groups. |

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players competing in high school, college or professional soccer, it was found that frequency of ball-heading and how recently they had participated in heading exercises interacted and caused deficits in attention and visuospatial capacity, suggesting that perhaps some transient cognitive problems may result from heading [51]. Stephens et al. [52] evaluated male soccer players aged 13–16 on 13 neuropsychological tests and recorded heading frequency during 1–3 games in a preliminary study and found that heading frequency did not significantly predict testing performance with the exception of the TAP test of divided attention. A second identical study by this group found that there were no differences between the groups [12]. Finally, Kaminski et al. [53] evaluated 393 female high school soccer players pre- and post-season using the Automated Neuropsychological Assessment Metric (ANAM) and had a designated individual from each team record the number of headers each player performed in each game. They did not find any significant correlation between test performance and the number of headers executed.

### *Long-term exposure*

The 11 studies examining the long-term effects of heading, head impacts and/or exposure to soccer included samples of elite, collegiate and/or professional level soccer players, which represent a population of athletes with longer and more intensive careers—and subsequently greater heading exposure—than younger athletes. These studies are summarized in Table VI. Matser et al. [54] looked at Dutch professional players and found greater memory, planning and perceptual deficits in forwards and defenders, players deemed to execute more headers in a season (they estimated the number of

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Table VI. Summarizes studies evaluating the cumulative, long-term effect of heading and head impacts on cognitive abilities in soccer players.

| Paper | *n* | Objectives | Subjects | Testing methods | Results |
|---|---|---|---|---|---|
| Tysvaer and Lochen [58] | 36 | Evaluate potential brain damage in former soccer players resulting from repetitive trauma of heading in soccer. | Former members of the Norway national soccer team. | WAIS, (Sub-tests: TMT A & B, HWRT, sensory-perceptual, motor tests, BVR, Form C). | Significant differences in Verbal IQ and Performance IQ in soccer players compared to controls. 81% of players tested displayed neuropsychological impairment on at least one of the tests. |
| Matser et al. [54] | 80 | To determine the presence of chronic TBI in professional soccer players and its relation to heading and/or head injury. | 53 current Dutch male professional soccer player and 27 elite track and swimming male controls. | RPM, WCST, PASAT, DST, TMT A & B, ST, BWT, subtests of the Wechsler Memory Scale (associate learning, logical memory and visual reproduction), CFT (Copy, Immediate Recall and Delayed Recall, 15WLT, BFRT, FDT, VFT, PT. | Soccer players showed decreased performance on verbal and visual memory, planning, visuoperceptual processing tasks compared with controls. Significant differences were seen on the CFT, Logical memory, visual reproduction. Forward and defensive players performed significantly poorer on FDT, CFT Immediate and Delayed recall, logical memory and visual reproduction compared with midfielders and goalkeepers. |
| Matser et al. [55] | 33 | To determine whether amateur soccer players have evidence of CTBI as a result of heading and head injury. | 33 amateur soccer players and 27 control athletes (runners, swimmers). | RPM, WCST, PASAT, DST, TMT A & B, ST, BWT, WMS, CFT, 15WLT, BFRT, FDT, VFT and PT. | Soccer players performed significantly poorer than controls on the CFT, DST, Logical Memory, Visual Reproduction and Associate Learning subtests of the Wechsler Memory Scale. |
| Matser et al. [56] | 84 | To determine the effects of headers and concussions on cognitive impairment in professional soccer players | Male professional soccer players from the Dutch premier league. | RPM, WCS, PASAT, WDSyT, TMT A&B, ST, BWT, Associate Learning, Logical Memory, Wechsler Visual Reproduction, CFT immediate and delayed recall, 15WLT, CFT copy, BFRT, FDT, VFT, PT. | More headers predicted poorer performance on CFT immediate and delayed recall, 15WLT, TMT, verbal and visual memory as well as focused attention. Number of concussions inversely related to CFT copy, BFRT and BWT. As number of concussions increased, visuoperceptual processing and sustained attention declined. |
| Downs and Abwender [57] | 61 | To examine whether soccer places participants at risk for neuropsychological impairment due to concussion, sub-concussive blows from heading the ball or a combination of this. | 32 soccer players (collegiate and professional): 15 males, 11 females and 6 older male current or former professional players and 29 swimmers (collegiate and masters): 7 male, 15 female and 7 adult male masters. | PASAT, FTT, CPT & WCST. | FTT & CPT: significant correlation between head impacts and hit reaction time and standard error WCST: swimmers outperformed soccer players in WCST categories and Total error scores. Higher Heading Index scores predicted performance on all tests. Soccer players were significantly worse at measures of conceptual thinking, particularly the older group. |

(*continued*)

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Table VI. Continued

| Paper | *n* | Objectives | Subjects | Testing methods | Results |
|---|---|---|---|---|---|
| Witol and Webbe [76] | 72 | To examine the effects of heading behaviour as well as that of estimated lifetime heading experience on neuropsychological test performance. | 60 male soccer players and 12 non-soccer-playing controls. | Shipley Institute of Living Scale, TMT A & B, PASAT, Facial Recognition Test, ROCFT, RAVLT. | High heading players took significantly longer to complete Trail Making Test A; Shipley Estimated IQ score differences were near significant in that High heading group had lower estimated average scores than the other groups. High lifetime heading took significantly longer to complete Trails A; significant differences were seen between the groups on the Shipley estimated IQ—showed that high lifetime heading scored significantly lower than the control group. |
| Rutherford et al. [59] | 22 | To gain some insight into the developmental history of any neuropsychological consequences of football play (heading frequency and/or head injuries). | 22 male soccer players from university soccer teams; their data was compared with university rugby players and non-contact athletes. | The Beck Depression Inventory, NART, ROCFT, WAIS-R Digit Symbol, WAIS-R Digit Span, ST, TMT, WMS Logical Memory and WMS VPA Immediate and Delayed, Sub-tests from the Zimmerman and Fimm's computerized test of Attention performance, WCST, Alternate Uses and the VFT (FAS), COWAT. | Soccer players scored significantly poorer than both other groups in the TAP Divided Attention sub-test. |
| Straume-Naesheim et al. [61] | 271 | Examine effect of previous concussions and heading exposure on neuropsychological testing performance. | Professional Norwegian soccer players competing in the 'Tippeligaen' | CogSport (SRT, CRT, Congruent RT, Monitoring, One-Back, Matching, Learning) | No significant effect of self-reported heading exposure on neuropsychological testing performance. |
| Kaminski et al. [62] | 71 | To investigate whether heading influences cognitive functioning in female soccer players. | High school and Division 1 Collegiate female soccer players compared with non-playing collegiate controls. | Wechsler Digit Span (forward + backward) and the HVLT. | There were no significant differences between players (at both high school and collegiate level) and controls on either cognitive test. Nor were there correlations between number of headers performed in a season and cognitive performance. |
| Rutherford et al. [60] | 73 | Determine whether soccer players exhibit neuropsychological impairments as a result of heading frequency and head injuries. | 73 male university soccer players compared with rugby and non-contact athletes. | WDsyT, TMT, TAP sub-tests, SCWT, ROCFT, WMS LM, VPA, WDST, WCST, AU, COWAT. | TAP Alertness scores, Working Memory and the COWAT were nominally predicted by the interaction between number of head injuries and heading frequency. |
| Straume-Naesheim et al. [77] | 548 | The objective was to determine whether minor head trauma in elite soccer matches causes measurable impairment in brain function. | 141 players who later had a head impact during the subsequent seasons, 48 of whom were re-tested at the end of the season. | The Post-concussive Symptom Scale was administered at baseline and follow-ups. Neuropsychological Performance was assessed with the CogSport testing battery (psychomotor function, decision-making, simple attention, divided attention, working memory). | Significant difference for all neuropsychological tests between the head impact and control group and significant decrease in performance on the follow-up tests of psychomotor function and decision-making. Even 1 year later, players experiencing a head impact showed an increase in reaction times compared with their control group and performed significantly more poorly on the decision-making task. |

headers performed per game and multiplied this number by the number of games in a season). Matser et al. [55] also screened a group of amateur soccer players to determine whether deficits were evident in this population in addition to professional players; the authors reported amateur soccer players were significantly impaired in attention and memory. It was also determined that lifetime exposure to heading was related to cognitive deficits where the professional players reporting the highest prevalence of heading over the course of their careers were most adversely affected in tests of verbal and visual memory as well as attention [56].

The long-term cognitive effects of repetitive, sub-concussive contacts as a result of heading was demonstrated by Downs and Abwender [57]. In this study, cognitive

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testing performance of current collegiate, professional, older professional or retired soccer players were compared to healthy controls. The control consisted of current collegiate, professional and master's level swimmers, as these athletes were considered comparable to soccer players in terms of physical abilities and training schedules, but without the risk of head injury. Swimmers performed better than soccer players in tests of conceptual thinking, while it was demonstrated that older or retired soccer players were significantly impaired ($p < 0.05$) in conceptual thinking, reaction time and concentration compared with all other groups, including the current younger soccer players. Tysvaer and Lochen [58] examined neuropsychological performance of retired soccer players formerly of the Norwegian National Team (aged 35–64) and found that they displayed significantly poorer verbal and performance IQ ($p < 0.05$) and were impaired on the Trail Making Test Part A and B ($p < 0.01$) as compared to a control group. In 2005 and 2009 studies, Rutherford et al. [59, 60] found significant differences between soccer players and controls in divided attention [59] and that the number of head injuries sustained interacted significantly with heading frequency to predict scores on alertness, working memory and language [60].

Straume-Naesheim et al. [61] reported no significant interaction of both self-reported heading exposure and previous concussions with neuropsychological testing performance, however their scores were not compared with any control group. Similarly, Kaminski et al. [62] found no significant differences in terms of cognitive performance between female collegiate and high school soccer players and non-playing collegiate controls.

*Biomarkers of brain injury after heading*

Five studies investigated the presence of biochemical markers of brain injury within the blood and/or cerebrospinal fluid (CSF) of soccer players after participation in heading exercises [63–67]. The most frequently investigated biomarker of the studies reviewed included S-100B and neuron-specific enolase (NSE). Of these five papers, three indicated elevated levels of S-100B after either soccer games where heading and/or head impacts occurred [64, 65] or after a heading session [63]. Specifically, Stålnacke et al. [64, 65] found that S-100B elevations correlated significantly with both the number of headers a player performed and the number of head trauma events (including collisions and falls) that a player experienced. These results were evident in both female and male soccer players. With respect to NSE, none of the studies indicated that NSE increased in response to heading exercises or head trauma. A summary of all findings can be seen in Table VII.

## Neuroimaging and neurophysiology

Six studies have applied advanced imaging techniques to examine the effects of heading in soccer players. Adams et al. [68] had a sample ($n = 10$) of active male intercollegiate soccer players (only two of whom had experienced a concussion) complete a magnetic resonance imaging (MRI) scan to determine whether head impacts during soccer play resulted in structural brain changes. It was reported that, compared with non-playing controls, the 10 soccer-playing participants had significantly decreased grey matter density bilaterally across the anterior temporal cortex, attributed to repetitive sub-clinical injury. These college-level players reported heading the ball anywhere from 2–20-times per game, in addition to the headers executed during training sessions, suggesting that the minor head impacts from heading that are inherent to soccer play can result in structural damage. These findings are in opposition to those of Jordan et al. [69], which did not report any significant MRI findings in members of the US Men's National Soccer team. Sortland and Tysvaer [70] used computed tomography to evaluate the brains of former members of Norway's national team and found that, of the 33 players recruited (mean age = 52), nine had significantly enlarged ventricles, 11 had significant cortical atrophy and three had significant cerebellar atrophy compared to normative measurements. Finally, in a recent original research letter by Koerte et al. [71], elite male soccer players in Germany without a history of concussion were evaluated using Diffusion Tensor Imaging (DTI) with a group of age, handedness and sex-matched swimmers. Significantly increased radial and axial diffusivity was found in soccer players, indicating myelin pathology and decreased white matter integrity in line with what is seen in mTBI patients.

A neurophysiological study was conducted by Tysvaer et al. [72] using electroencephalography with former National Team players in Norway to quantify long-term abnormalities due to heading. They found that 12 of the 37 players displayed slightly abnormal to abnormal EEG results, however, it is not stated if this was significantly greater than the four of 37 controls who exhibited slightly abnormal to abnormal results. Tysvaer and Storli [73] conducted a similar study on 69 active players competing within the Norwegian First Division League and 69 age-matched controls. Thirty-eight players reported acute symptoms of concussion in relation to heading; however, their EEG results did not significantly differ from those who did not have complaints, although the former group had a higher percentage of abnormal EEG results (16% compared with 3%). Results showed that 65% of the current players had normal EEG results compared with 87% of controls; however, it was not identified whether these differences were statistically significant.

## Discussion

Similar to many contact sports, soccer players are at risk of sustaining concussions from collisions with other players or the environment. The current review sought out to explore these issues. As reviewed here, there exists a range of game scenarios in which a soccer player is particularly vulnerable to sustaining a concussion—such as engaging in heading duels [6], goaltending and defending [30, 31]. History of previous concussion also appears to increase the risk of sustaining subsequent concussions [31]. With respect to identifying differences between male and female soccer players, the research is consistent in that the greatest proportion of concussions sustained by both male and female soccer players result from player-to-player contact, suggesting that aggressive play may have a role in the mechanism of concussive

Table VII. A summary of studies investigating the relationship between heading in soccer and serum and/or CSF concentration of biochemical markers of brain injury—namely S100-B and NSE.

| Study | *n* | Objective | Population | Methods | Results |
|---|---|---|---|---|---|
| Mussack et al. [63] | 119 | To determine whether S-100B levels were elevated after heading drills. | Experimental group: 61 male amateur soccer players (mean age 15.2); Controls: 58 male amateur soccer players (mean age 15.9). | Experimental group completed 55 minutes of heading drills; controls completed 61 minutes of regular exercise. Blood samples were taken before and immediately after these sessions. | After the heading session, S-100B levels were significantly increased compared to their baseline and this increase persisted up to 6 hours. This elevation was also significant compared with concentrations obtained from the control group. |
| Stålnacke et al. [64] | 28 | Investigate whether S-100B and NSE were elevated in connection with playing in a soccer game. | Male soccer players competing with elite Swedish teams (mean age $= 26 \pm 5$). | Blood samples were taken 1–5 hours before and then immediately after a game. Games were video recorded; two independent investigators estimated the number of head acceleration/deceleration events for each player (includes headers, jumps, falls and collisions). | There was a significant increase in both S-100B ($p < 0.001$) and NSE ($p < 0.001$) after the game compared to initial levels. S-100B levels were significantly correlated with number of headers and other trauma events; no significant correlation was found for NSE. |
| Stålnacke et al. [65] | 44 | To determine whether biomarkers of brain injury are increased in females after a soccer game. | Female elite soccer players in Sweden (mean age $= 23$, SD $= 3.0$). | Blood samples were taken from players before and immediately after a game. Two independent investigators analysed video footage of the game to estimate the number of head acceleration/deceleration events for each player (includes all types of headers, collisions, falls and jumps; non-header events were designated as 'other trauma events'). | S-100B and NSE concentrations were significantly increased after the game ($p = 0.000$). S-100B changes significantly correlated with all types of headers (pooled and separately) and other trauma events; NSE levels did not correlate with headers or trauma events. |
| Stålnacke et al. [66] | 19 | To examine whether controlled heading in soccer results in increased S-100B concentrations in the blood. | Adult male amateur soccer players, competing in local clubs. | Participants were randomly allocated to group A or B. Group A headed 5 balls dropped from a height of 18 m, while group B served as controls. Blood samples were collected before and after the session. | No statistically significant increases in S-100B were seen in either group; there was also no statistically significant differences in S-100B concentrations between groups A and B. |
| Zetterberg et al. [67] | 23 | To determine whether heading in soccer results in increased biomarkers of brain injury in the CSF and/or serum. | Male amateur soccer players. | 10 players headed the ball 10 times (mean age: 26); 13 headed the ball 20 times (mean age: 23) and 9 controls (mean age: 24). At 7–10 days post-session, participants and controls underwent lumbar puncture for CSF collection and had blood samples taken. | No significant differences in CSF or serum biomarkers were seen between players and controls or between the two heading groups. |

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injury [40]. Of the seven papers directly comparing concussion incidence rates in both males and females, six papers reported higher incidence in female soccer players [27–29, 34–36]. Furthermore, a 2002 study [31] calculated odds ratios associated with different potential risk factors and found that females were 2.6-times more likely ($p < 0.05$) to experience concussive injuries during a single season than males in the same league. It is important to note that the NCAA ISS and similar injury databases, which were analysed in many of the papers reporting incidence rates, have been shown to be valid and accurate reporting measures [74, 75]. Finally, two studies examined potential gender differences following acute concussion and they reported similar findings in that female soccer players performed worse on neuropsychological tests than male counterparts [45] and females reported significantly more symptoms of concussion [46].

Overall, studies that have examined concussions in soccer players support the larger body of sport concussion literature, which generally indicates that cognitive functions are temporarily disrupted following concussion and that there is the possibility of lasting deficits in those with a history of concussions. Impairments in verbal learning [47], memory [41], information processing speed [44] and visual processing [41] were evident in the literature. Conversely, the long-term effects of soccer participation and the influence of heading are less well understood than concussions. Nine papers evaluating soccer players' long-term neurocognitive performance suggested that this population of high-level current and former athletes suffers similar deficits to those who have experienced a diagnosed concussion. The most commonly reported cognitive deficits in these papers were related to attention [56, 59, 76], verbal and visual memory [51, 54–56], planning and decision making [54, 55, 77], visuoperceptual processing [54, 56], concentration and cognitive flexibility [57, 76]. This is of particular alarm due to the recent concern about potential links between concussions and sub-concussive head impacts and chronic traumatic encephalopathy (CTE). Although CTE is considered a distinct neurodegenerative disease and no definitive relationship has been established between brain trauma and CTE [4], the majority of identified CTE cases have been found in a small number of former athletes [78]. As such, this is an area that deserves further research.

While results of the studies investigating the effects of heading are intriguing, they may not provide an entirely accurate assessment. In terms of methodological rigor for the 14 studies investigating the short- and long-term effects of repetitive heading, 11 of these did not report whether participants had a previous history of concussions or included participants who had previously sustained a concussion and did not separate their results from players without a concussion. This may have confounded the results, skewing samples to seem more cognitively impaired, and one cannot discern the effect of heading exposure only. Furthermore, 11 of the 18 studies examining heading and cognitive performance relied upon questionnaires or interviews to determine participants' heading and/or concussion history. It is important that investigators do not rely solely on self-report as this method suffers from various biases in recall and may influence results by minimizing potential differences between healthy and concussed soccer players by possibly including non-concussed players in the concussed group and vice-versa. Finally, although studies of youth players attempting to determine the short-term effects of repetitive heading over the course of a season concluded that there was no significant effect on cognitive functioning, it is unlikely that such young players will have had sufficient long-term heading exposure that would yield the same deficits seen in studies of older soccer players.

While there were no studies examining the effect of acute concussions from soccer participation using neuroimaging modalities, six studies utilized neuroimaging or neurophysiological methods to evaluate the effect of repetitive heading and soccer exposure. Five of these six studies reported significant differences between soccer players and non-playing healthy controls. Adams et al. [68] reported decreased grey matter density within the anterior temporal cortex using MRI, while Koerte et al. [71] indicated decreased white matter integrity within the brains of elite soccer players. In terms of neurophysiological studies, the impact of long-term heading exposure is less clear, as abnormal EEG results were obtained in the soccer players compared with controls; however, it is not reported whether or not these results were significant [72, 73]. Overall, neuroimaging and neurophysiological studies are limited—particularly in terms of acute concussion where they are lacking completely—and, as such, it is an area of research that should be expanded upon in the future to determine whether there truly are adverse effects related to concussions and heading.

Additionally, five studies sought to determine whether the practice of heading results in or correlates with increased concentrations of biochemical markers of brain injury within the blood or CSF [63–67]. To date, S100B is the most commonly studied biomarker, with three studies finding significantly elevated levels after heading drills and that the number of headers performed was significantly correlated with S-100B concentration increases. The area of biomarkers still requires further expansion; however, it is a promising field with recent adoption of novel, more sophisticated technologies that has permitted a change in focus from the identification of single to multiple markers.

Regardless of the potential effects of concussions in soccer, additional efforts and resources are necessary in applying multi-faceted initiatives for head injury prevention in soccer. Some examples include standardized coaching principles of the consideration of safe and controlled methods of tackling or reducing contact and heading exposures during training. For young children in particular, Punnoose [79] discusses restricting the age at which children begin heading in soccer or regulating the number of headers they might perform during games in order to mitigate the potential cognitive difficulties later in life. Protective headgears warrant consideration as well, as it has also been previously suggested that headgear may reduce the peak impact force and head acceleration, thereby reducing the risk of concussions in soccer players [80, 81]. Finally, education is imperative; for example, Levy et al. [82] cite the importance of team trainers to protect players in both diagnosing and managing concussions and insuring strict adherence to return-to-play guidelines, since nearly half of concussed soccer players did not abide by recommended AAN return-to-play guidelines, thus placing themselves further at risk of serious TBI [32].

Legislation in terms of concussions and return-to-play guidelines might also prove to be helpful in terms of injury prevention, as outlined by Shenouda et al. [15]. In Washington, the Zackery Lystedt Law mandates that all parents, coaches and youth athletes receive education about concussions and must sign a 'concussion and head injury information sheet' prior to the start of practice or games. This legislation also states that players suspected of head injury must be removed from the field of play and receive written medical clearance before returning. Shenouda et al. [15] distributed a survey to individuals associated with the Washington Youth Soccer association regarding concussions and concussion management and, while some knowledge lapses did exist, most (90–100%) of the 391 respondents displayed general understanding of concussions and their severity. Legislation of this type is a good start to disseminate information about concussions to the general public and prevent concussed players from returning to sport too early and should certainly be adapted elsewhere, however it can be expanded upon by perhaps providing more rigorous concussion education for players, parents and coaches alike so as not to leave any doubt as to what a concussion is and how concussions should be properly handled.

## Limitations and future research

The current review was able to identify some important methodological recommendations in future research. See Table VIII for the summary of these recommendations. Very few of the studies employed control or appropriate comparison groups, therefore the inclusion of a comparison group (e.g. healthy uninjured soccer players who have not ever sustained a concussion or athletes with musculoskeletal or

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Table VIII. Recommendations for future research into soccer-related concussions and the effect of heading in soccer.

| Recommendations for future research |
|---|
| • Increased use of neuroimaging |
| • Use of subjects with a formally diagnosed concussion |
| • Reduced use of self-reports for concussion history or heading history |
| • Increased research into biomarkers and their relationship with both acute soccer-related concussions and heading |
| • Increased use of control groups |
| • Exclusion of players with previous concussions from studies investigating the effect of soccer exposure/repetitive heading |
| • Investigation of potential benefit from headgear or regulations limiting head contact in youth soccer |
| • Explore biological factors which may contribute to females' increased risk of concussions |
| • Comparison of concussions/their cognitive outcomes between different age groups |

orthopaedic injuries) drawn from the same population is highly recommended. Also, careful consideration of matching variables (e.g. sex, age, history of concussion, exposure time, etc.) is advised to control for confounders in planned analyses. Pre-injury or 'baseline' assessments have become more common in sport concussion research and this study design allows for comparison in performance before and after the injury or exposure. Furthermore, the implementation of longitudinal studies where researchers will be able to follow soccer players throughout their youth into adulthood would provide an opportunity to track the development of neuropsychological deficits and possible neurodegeneration that result from repetitive heading or concussions in concussions in soccer.

Comprehensive documentation of study sample characteristics and clearly defined operational definitions is essential to allow researchers to account, address and possibly control for such potential confounders [7]. Also, the means by which health history (i.e. self-reported or medical evaluation) or heading exposure in soccer (i.e. retrospective vs prospective) was captured should be reported and more effort should be made to use observational reports of heading rather than self-reports of heading history. Furthermore, more scientific rigor with respect to evaluating the effect of heading or soccer exposure on cognitive performance is needed. First, having an observer record the number of headers executed by players would be a far more accurate way of determining a player's heading exposure than simply having players provide estimates, which is subject to recall biases. Second, it may be appropriate to exclude players with previous concussions from studies that seek to determine the effect of heading or soccer exposure on cognitive abilities. At the minimum, controlling for prior history of concussion is essential.

Given that a total of 42 different neuropsychological tests were used by the studies investigating the effect of concussions and/or heading, it may be advisable for investigators in future research to adopt a set of standardized batteries when evaluating performance in these populations. Tools such as the ImPACT, Automated Neuropsychological Assessment Metrics (ANAM) and the Sideline Concussion Assessment Tool 2 (SCAT-2) have been developed for this specific purpose and the validity and reliability of these tools are well documented. Finally, more uniform testing procedures would allow results to be more readily compared to one another and make research more standardized.

There is a growing body of evidence among the larger body of sport concussion literature of differences between male and female athletes in concussion frequency and outcomes [27–29, 83–86]. Future studies should continue to investigate the underlying factors that may account for these differences between sexes. This is particularly important because females are participating in sports in greatly increased numbers [34, 87]. Since only 26 of 49 studies included female athletes, future research should focus on female only study samples or sample sizes large enough to examine potential differences.

Furthermore, it is evident that this area of research has not benefitted from the technologies associated with advanced neuroimaging. With only three imaging studies pertaining to long-term soccer exposure, this is a field that can be greatly expanded upon. Advanced neuroimaging techniques have recently been developed and implemented that have the potential to increase the sensitivity of standard MRI to detect both structural and functional abnormalities associated with concussion [88]. For example, Diffusion Tensor Imaging (DTI) has been used with football players [89] and could be used to better evaluate concussive injuries sustained by soccer players by allowing visualization of the extent of the axonal damage that has occurred. DTI could give insight into the potential underlying pathophysiology of concussion and better assess the potential cumulative effect of heading exposure in soccer players.

The application of novel, promising technologies such as serum biomarkers should be expanded on, with a greater focus in all sports, including soccer. Biomarkers such as S-100B and Neuron Specific Enolase (NSE) have been studied in terms of whether they are indicative of mTBI and if they have any predictive value in terms of mTBI outcome. A small number have sought to examine the relationship between serum biomarker presence and the practice of heading, with positive findings in some cases [63, 65]. Much like neuroimaging, the expansion and fine-tuning of serum biomarker research could prove to be an invaluable and objective tool for assessing both acute and repetitive concussions and the potential consequences of heading in soccer players.

## Conclusions

A review of the literature suggests that the acute cognitive effects of concussions in soccer are similar to those effects reported in the larger body of sport-related concussion literature. The unique aspect of soccer is the purposeful use of the head by players to control the ball; however, the long-term consequences of repetitive heading in soccer are not well understood. It was noted that only four studies investigated the neurocognitive outcomes of acute concussion in soccer players and this is an area that could be greatly expanded. Also, factors such as potential gender differences in the risk of concussion and outcomes from concussion require additional investigation. Given the varied nature of the methodologies used in the existing literature evaluating the effect of heading on cognitive abilities, no definitive statements could be made. Research in this area would benefit from carefully controlled longitudinal research designs and the application of novel, more refined technologies to provide further insight into the nature of concussions and potential consequences of long-term sport participation.

## Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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