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SYSTEMATIC REVIEWS

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Heading in football: a systematic review of descriptors, definitions, and reporting methods used in heading incidence studies

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ABSTRACT
The primary objective of this systematic review was to describe the number and type of heading descriptors used in all published studies which report on heading incidence in football. The secondary objective was to detail the data collection and reporting methods used in the included studies to present heading incidence data. Eligible studies were identified through searches of five electronic databases: Ovid MEDLINE, CINAHL, EMBASE, SPORTDiscus, and Web of Science, using a combination of free-text keywords (inception to 12th September 2023). Manual searching of reference lists and retrieved systematic reviews was also performed. A descriptive overview and synthesis of the results is presented. From 1620 potentially eligible studies, 71 studies were included, with the following key findings: 1) only 61% of studies defined a header with even fewer (23%) providing an operational definition of a header within the methods; 2) important study and player demographic data including year and country were often not reported; 3) reported heading descriptors and their coding options varied greatly; 4) visual identification of headers was essential when inertial measurement units were used to collect heading incidence data; and 5) there was a lack of standardisation in the reporting methods used in heading incidence studies making comparison between studies challenging. To address these findings, the development of a standardised, internationally supported, operational definition of a header and related heading descriptors should be prioritised. Further recommendations include the development of minimum reporting criteria for heading incidence research.

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Introduction

Over the last decade, an increasing number of scientific studies have been published regarding the short- and long-term effects of (repeated) heading in football on brain structure and function (Snowden et al. 2021; McCunn et al. 2021). This is in response to the reported association between football participation and the development of neurodegenerative disease in later life (Mackay et al. 2019; Russell et al. 2021; Ueda et al. 2023), which is often attributed to heading. However, attributing the development of neurodegenerative disease to a particular activity, such as heading, is challenging for several reasons, the most important being that heading incidence data are not routinely and consistently collected using validated data collection measures (Peek et al. 2023). Even when validated objective data collection methods are used, the variation in heading descriptors and reporting methods make the interpretation of heading data problematic, particularly when studies fail to document an operational definition of what a header is (Peek et al. 2023). Further issues arise when heading data are collected subjectively using player self-reporting, particularly for retrospective data captured many years after the end of a playing career (Harriss et al. 2018).

While the lack of prospective, longitudinal heading data does not prevent football associations globally from implementing heading guidelines as a precautionary measure (Union of European Football Associations 2020; Football Association England Heading Guidance 2023), the standardised collection of heading incidence data in football players is a crucial step in the investigation of the exact nature of the relationship between heading and any type of brain changes or diagnosable disease (Peek et al. 2023). Further, using a standardised method to collect heading data will enable a more ecologically valid, consistent, and nuanced understanding of heading incidence across all players (inclusive of age, sex

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and playing level). Standardised assessment of heading incidence can be used to better inform heading guidelines (including the possible implementation of age-related heading restrictions) (Union of European Football Associations 2020; Football Association England Heading Guidance 2023). These data may also inform other injury prevention initiatives (including heading coaching frameworks) to support the way that heading is taught and monitored. Currently the few studies that link heading with cognitive decline or the development of neurodegenerative disease base this hypothesis on self-reported heading incidence (Bruno and Rutherford 2021) or estimated age of first exposure to heading (Neal et al. 2022). While short-term recall of heading exposure has demonstrated mixed results for reliability (Catenaccio et al. 2016; Sandmo et al. 2021), reliance should not be placed on the recall of heading exposure collected many years or decades after the player has ceased playing (Peek et al. 2024). Thus, there is a need to develop a more objective, standardised framework for assessing heading exposure, similar to the quality criteria suggested for the conduct of research assessing the acute effects of heading (Peek et al. 2024 2024), and the standardised system for classifying injury-inciting circumstances in football (Aiello et al. 2023).

The overall purpose of this review paper was to collate and summarise the different methodological approaches reported in published studies of heading incidence to enable the future development of a standardised framework for conducting and reporting heading incidence research. Such a standardised framework will facilitate the comparison of heading data between studies and improve reporting of heading incidence and exposure data.

Objectives

The primary objective of this systematic review was to describe the number and type of heading descriptors (and their definitions) documented in all published studies which report on heading incidence in football. The secondary objective was to detail the data collection and reporting methods used in the included studies to present heading incidence data.

Methods

This review is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020 Statement) (Page et al. 2021) with the review protocol registered via Open Science Framework (https://doi.org/10.17605/OSF.IO/ZVWQF.) (Peek et al. 2023).

Table 1. Search strategy.

1. head*
2. soccer OR football
3. Game OR match
4. Pract* OR train*
5. 1 AND 2 AND (3 OR 4)

Search strategy

This systematic review identified studies for inclusion through searches of five electronic databases: Ovid MEDLINE, CINAHL, EMBASE, SPORTDiscus, and Web of Science, using a combination of free-text keywords (Table 1). The search strategy was specifically developed for this review to be as broad as possible based on previous reviews completed by the lead author and members of the authorship team (Peek et al. 2020, 2023). Manual searching of the reference lists of included studies as well as any retrieved systematic reviews with heading in football as a subject matter was also performed. Searches were completed for each database from inception until 12th September 2023.

Eligibility criteria

Only studies reporting original data on heading incidence during competitive match play or practice sessions which were published in a peer-reviewed journal in English (or other language if an English translation was available) were included. Studies using small-sided game formats (with <11 players per team) were included if they were age-appropriate matches for child and youth players (such as under 10s playing 7 v 7) or if they replicated a similar set-up that players would be exposed to in usual football training sessions (such as 3 v 3 or 5 v 5). Studies including tournaments where a reduced number of players is part of the competition rules were excluded (such as a 5 v 5 indoor or outdoor competition). Additionally, studies related to futsal or beach soccer were excluded. Heading data collected in a simulated environment such as a laboratory setting were also excluded. Studies which reported 'head impact' data without separating ball-to-head or head-to-ball impact data from other types of head impacts (i.e. head-to-head impacts) were also excluded. All methods of objective data collection were eligible for inclusion (including video or live coding, inertial measurement units or accelerometers). No eligibility restrictions were applied based on sex or age of participants, level of football participation, or the minimum number of matches/sessions reported in the study. Studies which only reported self-report or other subjective measures of heading incidence were excluded, unless the study also included an objective measure of heading incidence. Review papers or commentary articles were excluded but their reference lists were checked manually for any additional studies.

If more than one paper was published related to the same participants, then all the descriptors were extracted from the first published paper with only additional descriptors (and/or descriptors with differing definitions) being extracted from any subsequent papers.

Study selection

All identified studies were imported into the Covidence Systematic Review Software (Veritas Health Innovation, Melbourne, Australia). The initial screening of titles and abstracts was completed by three members of the author team (KP, TEA, SD). Full text screening was then independently completed by two authors (KP and AR) with any disagreements resolved through discussion. Due to the nature of the review, methodological quality or risk of bias assessment of the included studies was not undertaken given that the focus of this review was on assessing reporting methods rather than the outcomes of the included studies, as reported in similar reviews of outcomes and measurement instruments (Mathioudakis et al. 2023). All studies that met the inclusion criteria progressed to data extraction.

Data extraction

An initial data extraction form was created for this review by the first author (KP). This form was pilot tested by the author team using a sub-group of nine studies and revised following group feedback and discussion. Once the author team had approved the final data extraction form, an online training video on how to extract data was created (KP) and circulated to all authors with seven authors (KP, AS, TEA, AR, SD, JG, TM) involved in the primary data extraction of all included studies. Extracted data were then reviewed for consistency and accuracy in reporting by two authors (KP and AR). Extracted data included (where reported) study and participant demographics such as the year data were collected (as well as date of publication), country (or countries) that the study was completed in, the type of tournament or league (particularly if data were collected from national or international matches), playing level (categorised as professional, semi-professional, amateur-academy/collegiate, and amateur-grass roots/community), number of players per team (for match data), whether match and/or practice data were collected, numbers of teams and/or players included in the study, as well as sex and age or age group of players. In addition, the definition of a header as well as other head impact types as described in each included study was extracted. If an operational definition was reported in the methods this definition was extracted first, however, where such terms were not defined in the methods, the introduction and abstract were reviewed to extract data on how these terms were described. Finally, match and/or practice heading incidence data and data collection methods (as well as evidence of reliability/validity), types of heading descriptors reported (and their definition) as well as any other non-heading related descriptors (and their definition), head impact magnitude data and measurement device (where used, including evidence of validation) and data reporting methods were also extracted.

Data synthesis and analysis

Cohen's kappa coefficient was used to assess the level of agreement between the independent raters (KP and AR) when conducting full text screening to determine which studies should be included and excluded in this review: interpreted as 0 no agreement, 0.01–0.20 as none to slight, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1.00 as almost perfect agreement (McHugh 2012). We found almost perfect agreement of the screening between the two raters with a kappa of 0.81 (McHugh 2012).

Due to the outcomes of interest in this review, a descriptive overview and synthesis of the results is presented.

Results

From an initial search of 1620 potentially eligible studies, 71 met the inclusion criteria (Figure 1). The majority of studies were excluded at full text review for having the wrong outcome (such as reporting head impact data without separate data for headers or ball-to-head impacts) or wrong population including other football codes such as American football (often reported in the abstract as 'football'), as well as futsal or beach soccer. In terms of date of publication, the first study was published in 2002 ($n = 2$), with a total of 17 (24%) publications in the first 10 years (2002–2012; inclusive) and 54 (76%) studies published in the last 10 years (2013 and 2023; inclusive). Fifty-one percent of studies ($n = 36$) were published in the last 4 years alone (2020–2024) (Supplementary appendix I).

Demographics of included studies

Year of data collection: The first published paper reported heading data collected in 1999 with several studies reporting more recent data collection up until 2022. However, 29 (41%) studies did not report the date of data collection, meaning only the date of publication is known.

Country: Sixty-seven (94%) studies reported the country or countries where the data were collected. Most studies ($n = 54$, 76%) included data collected from Europe ($n = 27$) and the United States (US) ($n = 26$), with an additional study reporting data collected from the US and Canada. Seven studies were completed in Canada, three studies included data from Australia (with one also reporting data from India and an international tournament), one study reported data from Israel, one from Korea, Japan and the US, and one from Brazil.

Type of tournament or league and playing level: Sixty studies (85%) were conducted in national tournaments or leagues, four (5%) included international tournaments, and seven (10%) did not report these data. Thirty-one (44%) studies included amateur (academy/collegiate) players, fourteen (19%) included amateur (grassroots/community) players, one (1%) study included all amateur (academy/collegiate and grassroots/community) players, fourteen (19%) included professional players, one (1%) included amateur (academy/collegiate) and professional players, and three (4%) included semi-professional players. These data were not reported in seven (10%) studies.

Number of players per team: In 41 (58%) studies, data were based on matches with 11 players per team, 17 (24%) studies had a number other than 11 players per team (with the reasons being less players due to age-group regulations in child and youth football or small-sided games during practice sessions) and 13 (18%) studies did not report these data.

Match and/or practice data: There were 43 studies (61%) reporting match heading data only, with 17 studies (24%) reporting both match and practice data and 11 studies (15%) reporting practice data only. Where match data were reported, the number of matches ranged from 2 to 7147 with 11 studies not reporting these data. Where the total number of match hours was reported, this ranged from 154 to 4302 hours but the majority of studies ($n = 42$, 70%) did not report these data. Where studies reported practice data, the number of practice sessions ranged from 2 to 312 sessions, with eight studies not

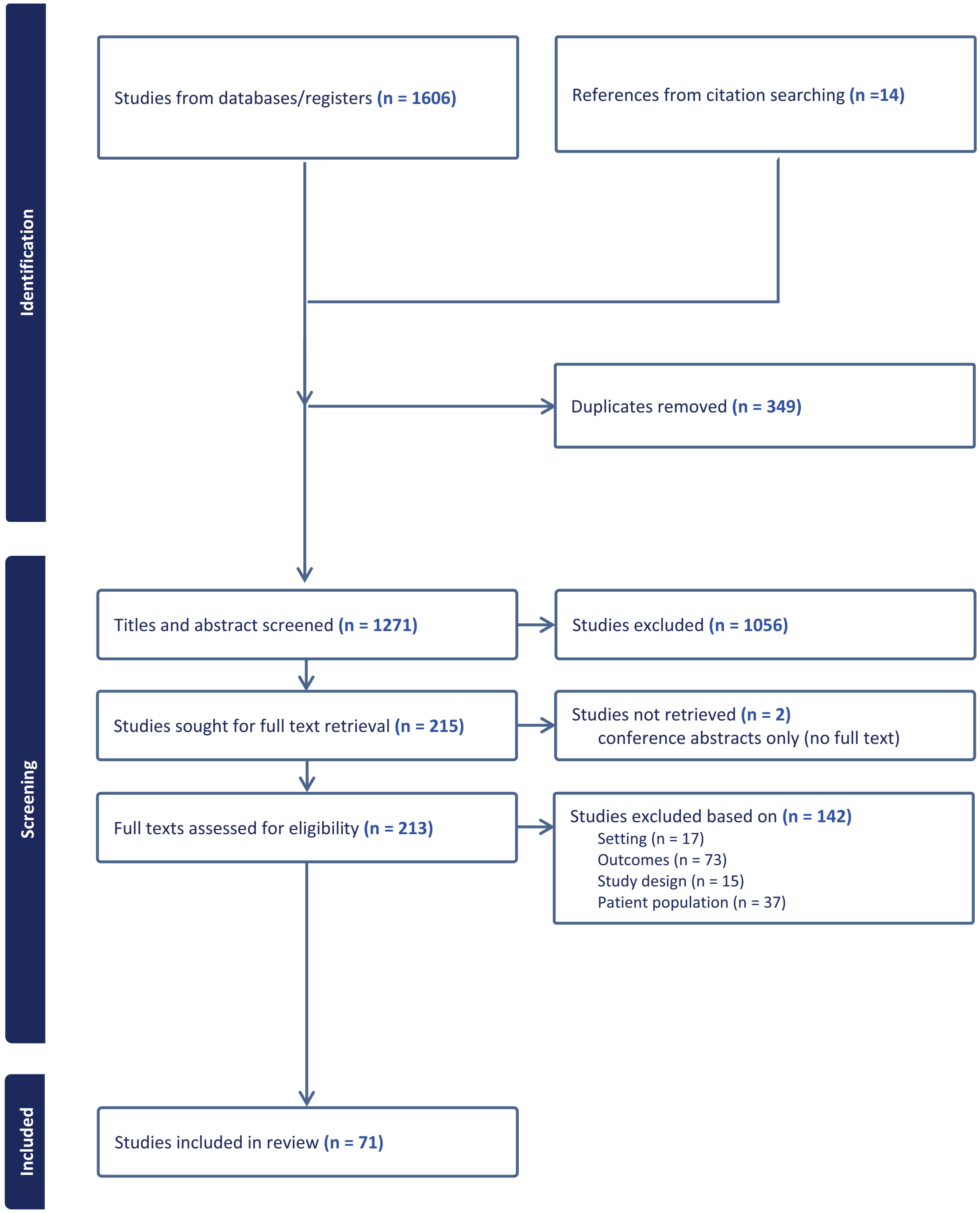

Figure 1. PRISMA diagram.

reporting these data. Where the total number of practice hours were reported, these ranged from 219 to 940 hours, with almost two-thirds of these studies ($n = 17$, 60%) not reporting these data.

Number of teams or players: The number of teams included in each study ranged from 1 to 480 (mean 21, standard deviation (SD) 83), with 23 (32%) studies not reporting these data. The number of players included in each study ranged from 4 to 1600 (mean 67, SD 120), with 12 (17%) studies not reporting these data.

Sex: Twenty-seven studies (38%) included only male players, 26 (37%) studies had only female players and 18 (25%) included both male and female players. However, when reviewing the studies that included only professional players ($n = 14$), only one (7%) study focused on female players (Stâlnacke et al. 2006) and two studies (14%) included both male and female players (Althoff et al. 2010; Langdon et al. 2022).

Age or age group of players: Thirty-two (45%) studies included youth players (aged <18 years including six studies with players aged 12 years or younger), 29 (41%) studies included only adult players and ten (14%) included both youth and adult players. Where the mean age of players was reported (49 studies), age ranged from 11.4 to 27.9 years (mean 18, SD 4). The youngest age-group of players was under-9s.

Position of the player heading the ball: Twenty-one studies (30%) reported the position of the player heading the ball. Fourteen of these studies categorised outfield players as defenders, midfielders and attackers with nine studies also including the goalkeeper in their recording. Other more detailed categorisation of playing positions included: goalkeeper, left and right back, centre-back, defender, defensive midfielder, offensive midfielder, midfielder, striker (Weber et al. 2022); goalkeeper; defensive player; wingback; central midfielder, other midfielder, winger, attacker, unknown (Straume-Naesheim et al. 2005); central defender, full back, central midfielder, wide midfielder, forward (Sarajarvi et al. 2020; Cassoudesalle et al. 2020; Roman et al. 2023).

Definition of headers and other types of head impacts

Of the 71 included studies, 43 studies (61%) described a header in their report (Table 2). The most common section to describe a header was in the introduction ($n = 26$) with one study describing a header in the abstract. There were 16 studies (23%) with a clear operational definition of a header in the methods, of which four studies either explicitly stated or implied that any ball-to-head impact was recorded as a header. In addition, six studies did not clearly define a header in their study, but they did define an unintentional ball-to-head impact (implying that only intentional ball-to-head impacts were recorded as headers). There were also five studies that separated ball-to-head impacts from other types of head impacts (such as head-to-head, ground-to-head contact). In these studies, it was unclear if ball-to-head impacts included both intentional and unintentional ball-to-head impacts. Finally, approximately one third of studies (26, 37%) included definitions of other types of head impacts (Supplementary appendix II).

Five studies (7%) also defined a heading duel and/or aerial duel (all within the methods section) (Table 3). Additionally two studies reported attempted or simulated headers which were defined as: 'An attempted header was defined as the purposeful action of a player's head towards the ball, but without any ball-head contact being observed (for example, a player who does not jump high enough to make contact with an aerial ball)' (Peek et al. 2021) or 'Simulated headers were defined as instances where the player feigned the motion of a header but did not make contact.' (Rutherford et al. 2009)

Reported heading descriptors

The most frequently reported heading descriptors (excluding head impact magnitude) are reported in Table 4, which included ball delivery type ($n = 21$), type or purpose of the header ($n = 15$), ball-head impact location ($n = 14$) and ball distance ($n = 8$). Many of the other descriptors were only reported in one or two studies such as angle of incoming ball, whether the team was in offense or defence, who delivered the ball, head height, jump height and purpose of the training drill (Table 4).

Other match related descriptors

Descriptors related to aerial or heading duels: These descriptors included whether there was observed body contact between two or more players when challenging for an aerial ball (Langdon et al. 2022; Weber et al. 2022, 2022), elbow position of the player performing the header and/or the opponent player during an aerial duel (such as below shoulder height; at shoulder height; above shoulder height; level of head) (Weber et al. 2022, 2022) as well as referee sanctions or actions (red card, yellow card, foul for or against) during duels (Sandmo et al. 2019; Cassoudesalle et al. 2020; Weber et al. 2022; Roman et al. 2023).

Other descriptors: Examples of other reported descriptors in the included studies were potential or verified head injury incidence/exposure (Beaudouin et al. 2020; Peek et al. 2021, 2021; Weber et al. 2022, 2022) and mechanism of injury (Weber et al. 2022; Porfido et al. 2022).

Data collection methods

Most studies (n = 45, 64%) collected heading (or ball-to-head) incidence data using some form of observation of headers as the primary source of data collection, with 26 studies (36%) using a type of inertial measurement unit (IMU) (Table 5). Thirty-two studies (45%) included two methods of collecting heading data, four of which used a subjective questionnaire, two compared live coding with video analysis and 26 compared IMU data with video analysis. Of the studies that used observation as the primary or secondary source of data collection, 16 (22%) reported some evidence to support the reliability or validity of their data collection method. Of the studies that used an IMU, eight of 26 studies (31%) reported primary evidence to support the validation of the IMU data, with many others citing studies where these data have been reported. All 26 studies included some cross-coding of IMU data to observed headers or ball-to-head impacts. Where the number of verified headers (or true-positive data) are reported (meaning that the IMU data were compared to observed headers), the IMU was able to detect headers in 49% to 100% of cases. However, the IMU also recorded many head acceleration events which were not headers (or ball-to-head impacts). For example, in studies where this is reported the percentage of IMU data which were not coded as headers (or ball-to-head impacts) ranged from 2% to 54% (although eight studies (31%) did not report these data) (Table 5). In addition, 18 studies (69%) also used a trigger threshold meaning that only head impact data above this threshold was recorded by the IMU. The trigger threshold ranged from 3.5 to 16 g.

Reporting methods

All 71 studies reported the total number of headers (or ball-to-head impacts). However, of the 60 studies reporting match headers, only 9 (15%) studies report the heading incidence rate using a comparable and commonly reported exposure metric of *per 1000 match hours*. Of the 28 studies reporting practice headers, only two (7%) presented a heading incidence rate using a similar reporting metric of *per 1000 practice hours*.

Table 2. Descriptions and operational definitions of a header extracted from the included studies.

Study reference	Section	Study definition or description of a header
Descriptions of a header		
Filben et al. (2021)	Abstract	"Soccer players are regularly exposed to head impacts by intentionally heading the ball."
Beaudouin et al. (2020)	Introduction	"Football is the only sport, in which players purposefully use the head to play the ball."
Bonn et al. (2021)	Introduction	"Soccer is unique to other sports in that players use their head to direct the ball, a technique referred to as purposeful soccer heading."
Catenaccio et al. (2016)	Introduction	"Heading – use of the unprotected head to direct the ball during game play.
Chrisman et al. (2019) (Chrisman et al. 2016).	Introduction	"Soccer is unique in that players use their head to propel the ball."
Filben et al. (2021)	Introduction	"Headers (i.e. players intentionally striking the ball with their heads)"
Forbes et al. (2016)	Introduction	"Soccer is an especially unique sport in that it requires purposeful heading for the advancement of the ball and success of game strategy."
Harriss et al. (2018)	Introduction	"Soccer is the only sport where players use their heads to direct and control a ball (heading)."
Kaminski et al. (2020)	Introduction	"Purposeful heading involves the deliberate and intentional use of the head to advance the ball as "to shoot, pass, and/or clear"
Kaminski et al. (2007)	Introduction	"Soccer is unique because its participants purposely use their heads for passing, shooting, and stopping the soccer ball."
Kenny et al. (2022)	Introduction	"Soccer is also a unique sport where players purposefully and voluntarily use their unprotected heads to manipulate the direction of the soccer ball for both offensive and defensive plays."
Kern et al. (2022)	Introduction	"Soccer players actively expose themselves to repetitive head impacts (RHI) by purposefully heading the ball in order to control, deflect, and redirect it in play."
Kontos et al. (2011)	Introduction	"Soccer is unique in comparison to other sports, as it is the only sport where participants purposely use their head to propel the ball. Players may head the ball to pass to another player, move the ball down the field, or score a goal."
Langdon et al. (2022)	Introduction	"Football is also unique in that players are allowed to use the head to play the ball."
Peek et al. (2021)	Introduction	"Purposeful heading is an integral skill where players deliberately use their heads to re-direct the ball."
Reeschke et al. (2023)	Introduction	"The intention to use the head to play and control the ball is unique to football."
Rich et al. (2019)	Introduction	"Heading is a common soccer activity occurring when players intentionally strike the ball with their head, exposing them to repetitive head impacts."
Rutherford et al. (2009)	Introduction	"Heading is a common soccer activity occurring when players intentionally strike the ball with their head"
Sandmo et al. (2020)	Introduction	"Soccer is unique in that voluntary and unprotected use of the head, in the form of heading the ball."
Sandmo et al. (2019)	Introduction	"Repetitive head impacts are common in football due to the sport's unique feature of purposeful heading of the ball with the unprotected head."
Sattari et al. (2023)	Introduction	"Soccer is a sport that involves repetitive heading, with players using their unprotected head to manipulate the ball."
Segars et al. (2023)	Introduction	"Soccer is different from other sports because athletes intentionally direct the ball with their head, using a skill known as a header."
Sokol-Randell et al. (2023)	Introduction	"It is the only sport in which players purposefully use their unprotected head (termed header) to play the ball for both offensive and defensive purposes."
Stalnacke et al. (2004)	Introduction	"The head is purposefully used to direct the ball in ordinary soccer play"
Stephens et al. (2010)	Introduction	"Heading"—intentionally playing the ball using the head."
Straume-Naesheim et al. (2005)	Introduction	"Football is the only contact sport exposing a large number of participants to purposeful use of the head for controlling and advancing the ball."
Weber et al. (2022)	Introduction	"Football has been the only contact sports in which players use the head for controlling and transferring the ball."
Operational definition of a header		
Sarajarvi et al. (2020)	Methods	"A header is an action where a player is in contact with the ball with his head, in this study, only the actions where a player intentionally contacted the ball were considered."
Tomblin et al. (2021)	Methods	"Headers, characterized by the athlete intentionally contacting the ball with their head during play"
Andersen et al. (2012)	Methods	"Headers were defined as when two or more players from different teams competed for the ball ... in the air (headers)."
Huber et al. (2021)	Methods	"Head-to-ball (i.e., intentional heading of the ball, exclusive to soccer)"
Nevins et al. (2019)	Methods	"Intentional or unintentional contact between the player's head and the ball (header)"
Owen et al. (2011)	Methods	"Player contacts the ball using their head"
Patton et al. (2021)	Methods	"A head-to-ball impact was defined as purposeful heading of the ball by the player"
Patton et al. (2020)	Methods	"Head-to-ball impacts for which the head intentionally impacts the ball."
Porfido et al. (2022)	Methods	"Ball-to-head impacts were defined as any event during the match when the ball contacts the head of a player either intentionally or unintentionally."
Press and Rowson, (2017)	Methods	"Player intentionally headed the ball"
Rago et al. (2016)	Methods	"Headers (number of times where a player is in contact with the ball with his head)"
Rahnama et al. (2002)	Methods	"Player makes direct contact with the ball using the head". "Jumping to head: Player leaves the ground before making direct contact with the ball with the head."
Roman et al. (2023)	Methods	"Purposeful headers were defined as when the player made an intentional action of moving their head towards the ball to redirect it."
Sandmo et al. (2021)	Methods	"A heading event was defined as any incident where a player intentionally headed the ball."
Uebersax et al. (2020)	Methods	"...every ball that was intentionally touched with the head was counted as a header."
Weber et al. (2022)	Methods	"All headings (every head contact or intended or attempted head contact situation with the ball of different players in the match) were monitored"

For this calculation, only 7 studies explicitly reported match exposure hours used in their calculation (although all reported the number of matches). For practice heading incidence rate per 1000 practice hours, both studies reported the actual number of practice sessions and exposure hours used in their calculation. Further, the way in which exposure hours were calculated also varied with most studies using gross calculations based on the number of players on the pitch or within a practice session, rather than calculating exposure on an individual player basis. Additionally, some studies included

Table 3. Definition of heading duel and/or aerial duel from the included studies.

Study	Heading duel	Aerial duel
Cassoudesalle et al. (2020)	See aerial duel definition	"…aerial duel corresponded to two opponents who were jumping for heading the ball (i.e. heading duel)."
Peek et al. (2021)	"A heading duel was defined as 2 or more players competing for a header in close enough proximity that physical contact between the players was observed."	Not reported
Roman et al. (2023)	"Heading duels were defined as when another player also made an attempt to head the ball by purposefully moving their head towards the ball. This second player must also have been within close enough proximity to make physical contact with the player heading the ball (such as shoulder-shoulder contact)."	Not reported
Reeschke et al. (2023)	"Heading duel: contact to another player, contact to teammate or opponent."	Not reported
Uebersax et al. (2020)	"We defined a duel as a situation with one player trying to conquer the ball from his opponent by tackling or blocking."	"Classified air duels as situations with at least one player jumping vertically and one opponent nearby (<1m)"

goalkeepers in their calculations whereas others excluded goalkeepers, providing the rationale that goalkeepers are rarely observed to head the ball (Harriss et al. 2019b).

Other methods of reporting included mean, median and/or range, or number of headers per match, practice session or per season. Mean, median and/or range, or number of headers were also reported per player, per team, per country, per playing level, per age-group, per header type, and per position. Other reporting methods included number of headers per player per minute or number of headers per player per hour or number of headers performed during different match scenarios or ball delivery methods. The number of headers for all player exposures (with match and practice data combined) was also reported. Other studies that used IMU data only reported headers or ball-to-head impacts that registered over a certain trigger threshold usually reported in g (likely calculated using the resultant value for peak linear acceleration although how the trigger threshold was calculated was rarely reported) or the authors categorised headers into high and low head impact magnitudes using a stated cut-off point.

Discussion

The overall purpose of this systematic review was to collate and summarise the different methodological approaches reported in published studies of heading incidence in football, which led to the following key findings: only 61% of studies described a header with even fewer (23%) providing an operational definition of a header within the methods; many studies did not report important study and player demographic data including year and country that data were collected; reported heading characteristics and their coding options varied greatly between studies; when IMUs were used to collect heading incidence data (and/or head impact magnitude data) the type of device often differed between studies with visual identification of headers also required; and finally, there was a lack of standardisation in the reporting methods used in heading incidence studies (only 15% of included studies reported heading incidence per 1000 match or practice hours) meaning comparison between studies is challenging.

Only 23% of studies reported an operational definition of a header in the methods of their paper, with 39% of studies not defining a header at all. Although many studies used the term 'purposeful header' to distinguish between deliberate head-to-ball contact and unintentional ball-to-head impacts, not clearly defining a header is problematic for several reasons. Perhaps the main reason is that headers and unintentional ball-to-head impacts are fundamentally not the same thing. In particular, heading is considered a skill-based activity, unique to football, which can determine whether matches are won or lost. It has been reported that 18% to 28% of goals are scored from a header in men's and women's international football (Peek et al. 2023) with additional headers used to block shots or disrupt possession. Whereas unintentional ball-to-head impacts are not a desired skill in football, and are more likely to lead to higher head impact magnitudes and a higher risk of head injury than intentional ball-to-head contact during heading (Perkins et al. 2022). With calls to ban heading in young age groups or even across all levels of football (Duru 2018; Tarnutzer 2018), being able to distinguish between intentional and unintentional head contact is important if we are to clearly understand the acute injury risk as well as the long-term burden posed by heading, separate from other types of unintentional head impacts. Four studies explicitly stated or implied in the methods that any ball-to-head contact was recorded as a header with a further five studies reporting ball-to-head impact data in the results without distinction. Several other studies were excluded because they did not separate types of head impact at all (Lynall et al. 2016; Lee et al. 2021). Given the growing scientific concerns around the long-term burden of heading, reviewing strategies that could reduce the frequency of heading (particularly in young players) as well as trying to minimise or eliminate all other types of unintentional head impacts in football should be explored. Therefore, it is important that all head impacts in football are not seen as analogous in the assessment of risk particularly where this is used to inform risk mitigation strategies as it is likely that each head impact type will require a different approach. For example, it has been reported that unintentional head impacts lead to higher head impact magnitude than headers, which could be important for determining head injury risk criterion (Perkins et al. 2022). In addition, while the most common mechanism of an acute head injury (such as concussion) in football in both men and women is from player-player contact (i.e. elbow-to-head contact) when two or more players are competing for an aerial ball, women appear more likely to be injured by the ball itself, including both intentional and unintentional ball-to-head contact, whereas headers are rarely reported as a cause of

Table 4. Heading Descriptors and their reporting options.

Descriptor	*Explanation*	Studies reporting this descriptor and their reporting options							
Action of player	*The movement action of the player performing the header or the opponent player in a duel*	a) player; b) opponent player. No jump; while moving; using run up speed; while running (Weber et al. 2022).	Jumping or standing header (Filben et al. 2022)	Jump or non-jump (Kenny et al. 2022)					
Angle of incoming ball	*Angle of flight of the incoming ball before it is headed*	<0 deg; 0–40 deg; 40–90 deg (Weber et al. 2022).							
Attack or defence	*Whether the team of the player who headed the ball were in attack or defence*	offense, defence (Weber et al. 2022).							
Ball deliverer	*Ball deliverer is the player who delivered the ball to the person performing the header*	ball from team member; ball from opponent player (Weber et al. 2022)							
Ball delivery type	*How the ball was delivered prior to the header*	free play; corner kick; throw-in; free-kick, goal kick (Beaudouin et al. 2020; Filben et al. 2021; Peek et al. 2021, 2021; Weber et al. 2022; Roman et al. 2023; Reeschke et al. 2023) Plus high pass/ball, header, cross, ground ball (Weber et al. 2022) Plus cross, attacking pass, chipped (Sarajarvi et al. 2020)	Corner kick, Deflection, Punt, Goal kick, Pass in air, Free kick, Throw-in (Brooks et al. 2021)	Bounce, Secondary header, Punt, Throw-in, Goal kick, Corner kick, Kick (Caccese et al. 2016)	(Short and long) kick, throws or headers (Filben et al. 2021, 2022)	Kick (long >10ft or short <10ft), throw (overhead or underhand), head (self or team-mate) (Miller et al. 2020)	corner kick, Punt (or drop kick), throw-in, free kick (Harriss et al. 2019b), deflection, pass in air, shot (Harriss et al. 2019a)	long kick, short kick, overhand throw, underhand throw, player (the ball hits another player before impacting the head), ground (ball hits the ground before contact with the player) (Kenny et al. 2022)	Goal kick (>17m); corner kick; player pass (<5m, 5-10m, 10-20m, >20m); throw-in; lob/chip, bouncer ball (Langdon et al. 2022);
Ball distance	*Distance the ball travelled before it was headed*	<5 meters; 5–10 meters; 10–20 meters; >20 meters (Beaudouin et al. 2020)	long kick = >10m short kick = <10m[37] (Kenny et al. 2022);	Long (>30m) or short (throws, high velocity (from GK) (Koerte et al. 2017)	close range (≤10 m), medium range (11–25 m), and long range (≥26 m)[40](Peek et al. 2021)	<5m, 5-20m, 20-50m, >50m[41](Reeschke et al. 2023)	close range (≤5 metres), medium range (6–19 metres) and long range (≥20 metres) (Roman et al. 2023).	Headers classified as short and long headers based on the distance of the incoming ball and force when heading (Sandmo et al. 2019)	very short (<5m), short (5-15m), medium (15-30m), long (>30m)[24] (Weber et al. 2022)

(*Continued*)

Table 4. (Continued).

Descriptor	*Explanation*	Studies reporting this descriptor and their reporting options						
Ball-head impact location	*The location on the player's head used to perform the header*	frontal; parietal; occipital; temporal; facial (Beaudouin et al. 2020; Weber et al. 2022, 2022; Reeschke et al. 2023)	top head, side head, forehead (Filben et al. 2022)	front, top, side, back, face (Harriss et al. 2019b, 2019a)	forehead; top; side (left/right), back (Kenny et al. 2022)	Forehead; Back of the head; On top of the head; Side of the head; Face (Peek et al. 2021, 2021; Langdon et al. 2022; Roman et al. 2023)	head, neck or face (Sandmo et al. 2019)	head, neck, or face frontal, right frontal, frontal/ crown, face (Sandmo et al. 2019)
Consequence of header	*What happened immediately after the header*	action successful or unsuccessful (Filben et al. 2021)	linear or rotational (ball direction) (Langdon et al. 2022)	goals scored by a header and possible goals saved from a header (Peek et al. 2021).	goal, shot or shot blocked and whether the team whose player headed the ball retained possession of the ball (Roman et al. 2023).	possession, no possession, progress or prevention of spatial progression, prepare or prevent goal scoring opportunity, goal scored (Sarajarvi et al. 2020)		
Head height	*Height of the head when the ball made contact*	head below the pelvic area, head above pelvic height (Weber et al. 2022)						
Jump height	*The height of the jump of the player or opponent player in an aerial duel.*	same height; higher jump of player; higher jump of opponent player (Weber et al. 2022)						
Match score	*Match score at the time of the header*	number of goals for each team (Roman et al. 2023)	winning, losing, drawing (Weber et al. 2022, 2022)					
Pitch location	*Location on the pitch where the header occurred*	midfield, outer track, penalty area (Weber et al. 2022)	Pitch location annotated with x and y coordinates (Langdon et al. 2022)	defensive third, middle third, attacking third (Peek et al. 2021, 2021)	pitch was divided into nine different regions (Sandmo et al. 2019; Weber et al. 2022; Roman et al. 2023)	pitch divided into zones (Sarajarvi et al. 2020)		
Player localisation	*Localisation of the player relative to the nearest other player at the time of the header*	In front of opponent player; behind opponent player; next to opponent player (Weber et al. 2022).						
Player movement	*Movement of the player immediately before they performed the header*	none; to the ball; away from ball; to the side (Weber et al. 2022)						

(*Continued*)

Table 4. (Continued).

Descriptor	*Explanation*	Studies reporting this descriptor and their reporting options						
Time	*match time/clock or match period when the header occurred*	time each header occurred from the start of play (Roman et al. 2023)	0–15 min, 16–30 min, 31–45 min, 46–60 min, 61–75 min, 76–90 min[24 51] (Weber et al. 2022)					
Training drill	*The description and purpose of each drill within a training activity.*	technical training, team interaction, game play, position specific, set pieces, and other conditioning (Pritchard et al. 2023)						
Type or purpose of header	*The type or purpose of the header being performed*	clearance, pass or shot (Lamond et al. 2018; Filben et al. 2021) Plus, deflection (Kaminski et al. 2008, 2020; Forbes et al. 2016)	Passing, clearing, sliding ball, shot, picking-up the ball, -diving header (Weber et al. 2022),	Defensive; passing; flick-on; on-target (Langdon et al. 2022)	direct or flick headers (Salinas et al. 2009)	finishing headers, re-directional headers, long direct headers, short direct headers, and headers from in-air duels (Sandmo et al. 2019)	Clearance, flick on, interception, pass, shot (Tierney and Higgins 2021) Plus headed control (Sokol-Randell et al. 2023)	Active head, sliding ball, return pass, diving header, pick-up or running with ball (Weber et al. 2022),

injury in men (Blyth et al. 2021; Dave et al. 2022). Therefore, strategies that reduce the likelihood of acute injury from head impacts in football (such as yellow or red cards for deliberate elbow-to-head impact) (Beaudouin et al. 2019) will not necessarily be the same as strategies aiming to reduce the long-term burden of heading (Peek et al. 2023). Recently, FIFA created the 'FIFA Football Language' (which includes an added medical coding focused on potential injury situations) as an open-source, standardised framework for the future analysis of football. This includes operational definitions to clearly define each player and match action (FIFA). Although aerial duel and physical duel are clearly defined in the FIFA Football Language, a header currently is not. Where studies included in this review did define a header, the most common element in these definitions is that heading is a footballing skill, one that involves purposeful/deliberate/intentional head-to-ball contact, aimed at redirecting/deflecting/propelling/controlling the ball. It follows that standardising the definition of a header should be prioritised.

If we consider that one purpose of heading incidence research is to provide an overview of heading incidence across different playing ages, skill levels and geographical areas for both male and female players to potentially estimate heading incidence for players of similar demographics, then it is vital that a minimum reporting standard is achieved to further facilitate the accurate collection of data but also the ability to compare these data between studies. Forty-one percent of studies in this review did not report the date that data were collected, meaning only the date of publication is known. This lack of reporting means that these heading incidence data cannot be used to explore heading incidence at particular time points. This impairs assessments even at a very broad level, for example, to explore whether heading guidelines or public concerns on the long-term effect of heading have had any impact in reducing heading incidence in match and practice sessions over time. Additionally, 18% of studies did not report the number of players per team. Although in most cases this could be assumed to be 11 versus 11, based on other reported details (such as age-group and competition level), these data should not be omitted. While most studies reported the age group of players (particularly at child and youth level), only 30% of studies reported heading incidence per playing position, and where they did, there were variations in how playing position was categorised and whether the goalkeeper was included. With evidence suggesting that defenders (particularly in men's and boy's football) head the ball more often than other playing positions (Peek et al. 2021, 2023) and appear most at risk of developing a neurodegenerative disease (Russell et al. 2021), this should be considered important information.

The most commonly reported heading descriptor was ball delivery type ($n = 21$), and, although there were many similarities between coding options between studies for this descriptor, there were also a few differences. For example, many studies included the option of a goal-kick, throw-in, free kick, corner kick and free play, whereas other options included bouncer ball or high-pass ball, options which may be less obvious to interpret without a clear definition (which was not always reported). Although the FIFA Football Language (FIFA) now includes many of these player and match actions, more widespread knowledge and use of these standardised terms within the published literature is encouraged. The distance the ball travelled prior to the header was reported in eight studies. This information could be considered important given that current Heading Guidelines in England limit the number of high-force headers during training for all players (Football Association England Heading Guidance 2023) (with headers from long-balls including corner and goal kicks often considered in this category). The consequence of the header was only reported in five studies, with variation in what was reported (goal, blocked shot, retained or lost possession, successful or unsuccessful). One approach to reduce the burden of heading across a playing career is to explore what constitutes a high- or low-performing header so that high-performing headers can be prioritised, and low-performing headers can be reduced or eliminated. What defines a high or low-performing header will likely be based on outcome or consequence of the header; therefore, further work in this area is encouraged.

While all studies recorded heading incidence through observation (whether this was via live coding or video analysis), only 22% reported evidence of intra-rater or inter-rater reliability. Further, 26 (37%) studies also used an IMU to record incidence, with most also reporting head impact magnitude during heading. Just over half of these studies provided primary evidence for the validation of the device to accurately record head impact magnitude data (although many cited other studies where this had been completed, in some cases with an overlap in author group). However, what appears consistent in the reporting is that IMUs, such as instrumented head bands or mouth guards, should not be used to collect head impact incidence data (including headers) without verification of the impact event (Harriss et al. 2018; Sandmo et al. 2019). For example, in the study by Saunders et al. the research team attempted to find every one of the 20,954 impacts recorded by their IMU on film (Saunders et al. 2020). They were able to verify 1730 (8.3%) with most impacts not able to be verified because no impact could be seen on film (false positive) or because the player was outside of the camera view (Saunders et al. 2020). In addition, there were reported differences in the IMU trigger criteria which may significantly affect the number of recorded head impact incidence data available to be reviewed. For example, a study of heading incidence among football players that uses a 16 g trigger criterion will likely produce a lower incidence rate than an identical study that uses a 3.5 g trigger criterion, as some header magnitudes fall in the 4–10 g range. Thus, a lack of standardised IMU configurations means that inter-study comparisons become more challenging. Finally, if we revisit the reason that heading incidence papers are an important addition to the heading-evidence base, particularly as a means to estimate heading frequency over time, standardisation is needed in reporting methods which enable a comparison of data between studies. The timely creation of a standardised framework for reporting heading incidence is perhaps more important than ever given that 51% of the included studies in our review were published in the last four years alone (2020–2023 inclusive). If this trend is to continue then it is vital that future heading exposure research uses the same operational definitions of their included descriptors so data can be compared between studies and

Table 5. Studies using an inertial measurement unit as well as observed headers to report heading incidence.

Study	Type of data reported	Device	Validation of head impact magnitude data	Validation of heading incidence
Brooks et al. (2021)	Match	GForce Tracker (Artaflex Inc., Markham, Ontario, Canada) secured at the back of the head with a headband. – 7g trigger threshold	No primary validation data are reported.	Head impacts were confirmed using video analysis. A total of 434 verified headers. Data on unverified headers are not reported.
Caccese et al. (2016)	Match	Triax Smart Impact Monitor (SIM), SIM-G model (Triax Technologies Inc., Norwalk, CT) was used in conjunction with custom headband attachment	"Validation data suggest the SIMs consistently and accurately report peak linear and rotational acceleration" (Karton et al. 2016; Oeur et al. 2016)	"There were 588 impacts recorded, and 380 impacts used in data analysis."
Chrisman et al. (2016)	Match	xPatch (x2biosystems.com)-15g trigger threshold	"We also performed a separate validation study comparing xPatch measurements from a Hybrid III head form to a criterion standard (a laboratory-grade triaxial linear accelerometer. . . These data were then used to adjust the xPatch estimates to the criterion standard using the following equation: adjusted peak linear acceleration + (measured peak linear acceleration + 1.3066) / 7.625."	"There were 73 head impacts >15g recorded by the xPatch and confirmed through observation, almost half (45%) of which were due to heading." Number of non-verified head impacts were not reported.
Chrisman et al. (2019)	Match	xPatch (x2biosystems.com)-15g trigger threshold	"The technology in the xPatch is identical to that in the xGuard (a mouthguard sensor), which was validated by an independent biomechanics laboratory at Stanford University (Camarillo et al. 2013). We also performed a separate validation study (Chrisman et al. 2016), and data from our validation study were used to adjust the xPatch estimates using the equation: Adjusted PLA = (Measured PLA × 1.3066) − 7.625."	"Only impacts that were measured by the device and independently confirmed by an observer were included in the analyses." Number of non-verified head impacts were not reported.
Harriss et al. (2019a)	Match	GForce Tracker (GFT2), Artaflex Inc., Markham, Ontario, Canada)- secured at back of head with a headband- 7g trigger threshold	No primary validation data are reported.	"A total of 434 purposeful headers were identified from video analysis with matching events recorded with microsensors." No data reported on un-matched headers
Huber et al. (2021)	Match	Triax SIM-G head impact sensors secured in a neoprene headband and positioned just above the greater occipital protuberance- 16g threshold trigger	No primary validation data are reported. "As an impact counter, the SIM-G consistently recorded >85% of head impacts in 2 human head surrogate studies, and the video confirmation process described here is designed to remove false positives in real-life settings." (Cummiskey et al. 2017)	"Video and sensor data were aligned by filming a few seconds of a world clock website (timeanddate.com). Overall, the processing algorithm had a 52% accuracy . . . . The algorithm correctly classified 68% of video-confirmed impact events as true head impacts, and the algorithm correctly classified 54% and 31% of trivial and non-events, respectively, as "spurious" recordings."
Kern et al. (2022)	Match	xPatch, (X2 Biosystems, Seattle, USA) – 8g threshold trigger	No primary validation data are reported. References for validation (Siegmund et al. 2015; Tiernan et al. 2019).	"ICC analysis (κ=0.95, 95% CI [0.92–0.96]) revealed an excellent interrater agreement for the identification of header events from video data . . . . From 44,481 impacts recorded by the x patch sensors, 904 (i.e., 89.0% of header events determined on video) could be unequivocally assigned to video-identified headers."
Nevins et al. (2016)	Match	xPatch (X2 Biosystems, Seattle, USA) – 10g trigger threshold trigger	No primary validation data are reported.	"There were 125 head impacts recorded . . . Review of the video indicated another 39 (31.2%) impacts were spurious (no contact or change in movement). Additional filter elements reduced the proportion of false positives to 13.3% but eliminated 34 valid impacts."
Nevins et al. (2018)	Match	xPatch (X2 Biosystems, Seattle, WA, USA)	"In laboratory tests, sensor performance was assessed using a Hybrid III head form and neck . . . . Accuracy of the sensor varied inversely with impact magnitude, with relative differences across test conditions ranging from 0.1% to 266.0% for peak linear acceleration and 4.7% to 94.6% for peak angular acceleration when compared to a wired reference system."	"Of the 98 events classified as valid by the sensor, 20.5% (20 impacts) did not result from contact with the ball, another player, the ground, or player motion and were therefore considered false positives. Video review of events classified as invalid or spurious by the sensor found 77.8% (14 of 18 impacts) to be due to contact with the ball, another player or player motion and were considered false negatives."

(*Continued*)

Table 5. (Continued).

Study	Type of data reported	Device	Validation of head impact magnitude data	Validation of heading incidence
Nevins et al. (2019)	Match	xPatch (X2 Biosystems, Seattle, WA, USA)- 10g trigger threshold	No primary validation data are reported.	"In all cases where a precipitating event for the recorded impact was not apparent, the impact was considered a false-positive result and excluded from analysis." The number of false-positive data were not reported
Patton et al. (2021)	Match	Headband mounted SIM-G impact sensors	No primary validation data are reported.	"Sensitivity (i.e., recall) and precision (i.e., positive predictive value) were calculated . . . . For both females and males, head-to-ball impacts had the highest sensitivity of 49% (226/459) and 62% (780/1253), respectively."
Patton et al. (2020)	Match	Headband-mounted impact sensors (SIM-G; Triax Technologies)	No primary validation data are reported.	"40,352 sensor events were recorded . . . .9503 sensor events were recorded during scheduled game times . . . when verified game times were accounted for, the number of sensor-recorded events was reduced to 6796 . . . .further reduced to 2775 after exclusion of data from players who were not on the pitch and to 1893 after exclusion of data from players not in the field of view of the camera at the time when the sensor recorded the event. The final data set of sensor-recorded events represented 20% of the sensor-recorded impact events during scheduled game times . . . . Of the 1316 sensor-recorded impact events, most were head-to-ball impacts (78%)"
Sokol-Randell et al. (2023)	Match	Instrumented mouth guards (Prevent Biometrics, Minneapolis, MN) –5g trigger threshold	"Reported that an earlier study found the Prevent Biometric custom-fit iMG to perform best in laboratory dummy head form testing with lower mean relative errors of 4.9%, 4.6%, and 2.5% for peak angular acceleration, angular velocity, and linear acceleration, respectively (Liu et al. 2020). "	"In total, 133 video-verified headers were recorded . . . The raw agreement was 100.0% for the identification of headers comparing mouthguard data to video review." No data are presented on the total number of impacts recorded by the mouthguards in this study.
Segars et al. (2023)	Match & practice	Custom-fit mouthpiece with an accelerometer	No primary evidence of reliability reported. Validation study cited (Rich et al. 2019)	"Over the course of the season, there were a total of 724 head acceleration events recorded during the 44 practice sessions; 30.1% (218 of the 724 recorded events) were direct head impacts (i.e., included head contact) that were further analysed in the statistical models."
Filben et al. (2022)	Match & practice	Mouthpiece sensor containing a triaxial accelerometer and gyroscope embedded in acrylic, as described by Rich et al. (above)- 5g trigger threshold	Referenced that it is validated, but no primary validation data are reported (Rich et al. 2019).	"A total of 5831 mouthpiece recordings occurred during practice and game sessions while the players wearing the mouthpieces were visible on film. Of these 5831 recordings, 1164 (20.0%) were visually paired with an on-field contact scenario via film review."
Kenny et al. (2022)	Match & practice	instrumented mouthpiece sensor, designed by Wake Forest Center for Injury Biomechanics. – 5g trigger threshold	No primary validation data are reported.	"Of the 1307 head impacts confirmed via video, we could identify time-synchronized mouthpiece recordings for 1055 impacts. 206 video-confirmed impacts (15.8%) did not register on the mouthpiece sensors, indicating these impacts were likely below the 5 g threshold."
Lamond et al. (2018)	Match & practice	Smart Impact Monitor (SIM; firmware version 3.7; SIM-G, version 3.3; AP, version 0.9.150413; software, Triax Technologies, Norwalk, CT)- secured via headband – 10g trigger threshold	No primary validation data are reported. Cited the following references re: SIM validity (Karton et al. 2016; Oeur et al. 2016).	"The SIMs recorded 10,270 impacts during play; 627 of these impacts (6.1%) were visually verified as direct head impacts by researchers and included in the final data analysis. An additional 59 impacts were visually observed and recorded by the researchers but were not recorded by the SIM. These impacts may have fallen below the 10g threshold or may not have been recognized as head impacts by the SIM."

(*Continued*)

Table 5. (Continued).

Study	Type of data reported	Device	Validation of head impact magnitude data	Validation of heading incidence
Miller et al. (2020)	Match & practice	custom-instrumented mouthpiece	"The mouthpieces were previously validated in a laboratory setting, demonstrating good agreement between kinematic measurements of the mouthpiece and a gold standard head form; peak head kinematics were correlated with r2>0.98 for both rotational velocity and linear acceleration and r2=0.93 for rotational acceleration."	"Impact events observed in the video were paired with data collected by the mouthpiece. A total of 1,507 head impacts were observed on film. Of these, 763 were paired with mouthpiece impacts."
Press and Rowson, (2017)	Match & practice	XPatch (X2 Biosystems, Seattle, WA)- 10g trigger threshold	No primary validation data are reported.	"At a linear acceleration threshold of 10g, 16.3% of positive recorded impacts were true-positive results. This value was maximized at 34g, where 65.8% of positive recorded impacts were true-positive results. At this threshold, there were 383 true positive impacts, 199 false positives 15,963 true negatives, and 1320 false negatives.
Pritchard et al. (2023)	Match & practice	Mouthpiece sensor with a tri-accelerometer and gyroscope – 3.5g or 5g trigger threshold	"Head impact magnitude data: Linear acceleration (slope:1.02, r2:0.95), angular acceleration (slope:0.96, r2: 0.97), and angular velocity (slope:1.00, r2: .0.99) were strongly correlated with reference data from sensors located at the center of gravity of an instrumented National Operating Committee on Standards for Athletic Equipment (NOCSAE) head form type."	"A total of 4465 head impacts (*n*= 2618 spring, *n*= 1847 fall) were observed from film review. A total of 2457 video-verified contact events were recorded by the mouthpiece. Of these, a total of 464 events were excluded from the current analysis; 459 because no head contact occurred and five because they contained erroneous kinematic data inconsistent with the impact."
Rich et al. (2019)	Match & practice	Custom-fit mouthpiece with an accelerometer (ADXL377, Analog Devices, Norwood, MA, USA) and angular rate sensor (LSM6DS3H, STMicroelectronics, Geneva, Switzerland)- 5g trigger threshold	"For laboratory validation, data from the mouthpiece sensor was compared to standard sensors mounted in a head form at the center of gravity as the head form was struck with a swinging pendulum. Linear regression between peak kinematics measured from the mouthpiece and head form showed strong correlation, with r2 values of 0.95 (slope = 1.02) for linear acceleration, 1.00 (slope = 1.00) for angular velocity, and 0.97 (slope = 0.96) for angular acceleration."	"In field deployment, mouthpiece data were collected from four female youth soccer players and time-synchronized with film. Film-verified events (*n*=915) were observed over 9 practices and 5 games, and 632 were matched to a corresponding mouthpiece event. This resulted in an overall sensitivity of 69.2% and a positive predictive value of 80.3%."
Saunders et al. (2020)	Match & practice	XPatch (X2 Biosystems, Seattle, WA)- 10g trigger threshold	No primary evidence of reliability reported. Cited (Cummiskey et al. 2017)	"We went through every head impact recorded by the xPatch and attempted to find it on film. We started coding with 20,954 impacts and were able to verify 1730 (8.26%)."
Tomblin et al. (2021)	Match & practice	Custom-fit mouthpiece as described by Rich et al (Rich et al. 2019 -). 5g trigger threshold	Validation of head impact magnitude: As described by Rich et al. (Rich et al. 2019)	"935/954 true-positive events (98%)- mouthpiece and video review"
Filben et al. (2021)	Practice	Mouthpiece sensor with a tri-axial accelerometer and gyroscope – 3.5g (youth) or 5g (collegiate) trigger threshold	Referenced that it is validated, but no primary validation data are reported (Rich et al. 2019).	"All mouthpiece-recorded events were video-verified using a custom video analysis program developed in MATLAB (MathWorks, Natick, MA) that semi-automatically paired mouthpiece event timestamps with corresponding video times . . . . A total 165 of 567 film-verified headers." The number of unverified data was not reported
Hanlon and Bir, (2012)	Practice	HITS headgear- system has six (±250g) single-axis linear accelerometers (Analog Devices, Inc., Norwood, MA) placed tangentially to the head.	"Validated in a previous published study by same authors"(Hanlon et al. 2010).	"Games were videotaped for later analysis in determining what type of impact occurred at each downloaded time point." No data are presented on the number of paired or unpaired data between HITS and video
Sandmo et al. (2019)	Practice	In-ear sensor (MV1, MVTrak)	"Laboratory validation followed by controlled on-field evaluation and in-training on-field evaluation- for the laboratory tests, the random error was 11% for PLA, 20% for PRA, and 5% for PRV; the systematic error was 11%, 19%, and 5%, respectively."	"MV1 sensors recorded 2039 nominal head impact events. Of these, 15 events were confirmed on video analysis to be direct head impacts (from heading) . . . . However, the accuracy of the sensors for discriminating headers from non–head impact accelerative events in a controlled on-field setting was excellent."

jurisdictions. Reporting raw or total numbers of headers is rarely useful without the context of incidence rate (most commonly reported per 1000 hours), further divided into match and practice hours (not grouped), or per match or practice minute or hour. However, very few studies used a comparable metric to report their heading data. Even when incidence rate per 1000 match hours were reported, there were differences in the way these data were calculated with inconsistencies in whether the goalkeeper was included.

Limitations

It should be acknowledged that this review has some limitations. Firstly, our database search strategy excluded studies not published in English. Therefore, studies published in countries where English is not routinely used as the primary language to report scientific findings, would have been excluded before title and abstract screening. We also had a higher than anticipated number of included studies identified through reference list searching ($n = 14$), rather than being found in our database searches despite using very broad search terms. Many of these additional studies were coaching focused where heading incidence was one reported outcome. It is possible that the use of traditionally medically focused databases might not fully capture coaching studies. Although we included five different databases and a very broad free-text search strategy to overcome this limitation, further exploration of other databases should be considered in future reviews on heading.

Future research

Additional areas for research focus have been highlighted by this review. For example, few eligible studies were conducted outside of Europe and North America, with even less involving professional women. The incidence of heading in younger age groups (less than 10 years of age) is also rarely reported, with further research related to the outcome or consequence of a header being needed to inform performance-based heading risk mitigation strategies.

Conclusion

This systematic review has highlighted several key findings related to the conduct of heading incidence research. Most importantly, a standardised operational definition of a header supported at international level is urgently needed to align future research. Recommendations should also be explored regarding the minimum reporting criteria related to study and player demographics, heading descriptors and their definitions, as well as data collection and reporting methods. This should be a research priority to enable more accurate comparison of heading data in future research.

Disclosure statement

AS declares full time employment by FIFA. KP and JG have been contracted Injury Spotters for FIFA organised tournaments (2023). KP (Lead) TM and AS are members of FIFA's Heading Expert Group. TM is chairman of UEFA´s and the German FA´s (DFB) Medical Committee. TEA is member of the FIFA Scientific Advisory Board and Chief Medical Officer of the Football Association of Norway (NFF). All authors declare no other relevant financial or non-financial competing interests.

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Data availability statement

All extracted data are included in the paper. Copies of the data extraction excel spreadsheet or reference list of excluded studies are available from http://kerry.peek@sydney.edu.au.

Open scholarship

This article has earned the Center for Open Science badge for Preregistered. The materials are openly accessible at https://doi.org/10.17605/OSF.IO/ZVWQF.

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