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# Quantification of heading in adult football: a systematic review and evidence synthesis

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## ABSTRACT

**Objective** This study aims to evaluate the quantification of heading in adult football (soccer) across practice, game and laboratory settings. Additionally, it examines how variables such as technical categorisation, ball properties, gender, position, level and type of play influence acceleration, force, nature and frequency of heading.

**Design** A systematic review was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses-Protocols guidelines and registered with PROSPERO (CRD42021249268).

**Data sources** MEDLINE, ScienceDirect, SPORTDiscus, CINAHL, Web of Science, Scopus and ProQuest.

**Eligibility criteria for selecting studies** Studies published in English between 2000 and 2024 that quantified subjective and/or objective measures of acceleration, force, nature and frequency of heading in football were included.

**Results** Thirty-two articles met the eligibility criteria. Measurements of acceleration, force, nature and frequency were measured in practice and game situations; however, no study reported all measures synchronously from both practice and games in the same investigation. Differences in acceleration (linear/rotational), force, nature and frequency when heading were observed and influenced by gender, playing position, type of header, approach, preceding events, ball properties and neck strength. Acceleration and force were the highest from goal kicks, and a larger frequency of headers was exhibited in training than games. The nature of headers was difficult to report due to inconsistencies in the terms used across the literature to define the type of header or event preceding the header.

**Conclusion** Our findings inform the standardisation and accuracy of quantifying heading in football. Future research should focus on quantifying heading in uncontrolled scenarios using valid and reliable technology and verify ball-to-head impacts through video analytics to determine any relevant clinical thresholds for heading.

## INTRODUCTION

Heading is a crucial skill in football (soccer), frequently used during both attacking and defensive phases of play, which players must perform on demand.<sup>1–4</sup> While existing literature may explore the potential forces occurring during heading, thresholds are not yet fully established for elite football populations. Therefore, to explore heading in elite football, it is essential to accurately quantify the kinematics, including linear and rotational/angular accelerations, frequency and mechanisms of

## WHAT IS ALREADY KNOWN ON THIS TOPIC:

⇒ There is considerable debate on the risk of injury related to heading in football, with some studies focusing on quantifying associations with individual aspects of heading such as acceleration, force, nature and frequency.

## WHAT THIS STUDY ADDS

- ⇒ Acceleration during heading is influenced by factors such as gender, playing position, level of play, type of header, approach, preceding events, ball properties and neck strength. Such contextual factors are under-reported in the available evidence base.
- ⇒ Technological developments for measuring acceleration, force, frequency and nature exist but are limited in validity, reliability and usability, especially within elite environments.
- ⇒ Laboratory-based or model reconstructions have limitations in accurately reflecting heading in real-world, uncontrolled situations (ie, practice or game settings).
- ⇒ Findings highlight the lack of standardised research regarding the acceleration, force, nature and frequency thresholds that occur during heading in elite footballers.
- ⇒ Currently, there is no standardised process to accurately quantify heading in elite adult football.

## HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ Longitudinal studies are needed within elite adult football environments to determine clinically relevant thresholds for heading that contextualise mechanisms within the demands of the sport.
- ⇒ Heading during game play should be verified through video analysis to accurately categorise the nature of heading. This approach helps ensure precise reporting of frequency and mitigates technical limitations of wearable technology in capturing synchronised acceleration events.

heading. Recent studies have reported technological advancements that measure heading in terms of acceleration, force, nature and frequency.<sup>4,5</sup> These devices, however, require further validation for use in football environments. Initial scoping reviews do not provide a consensus on the most effective methods for quantifying heading or how these metrics vary with other associated variables in adult



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football during practice and games. It is important to recognise studies investigating head impact measurements in sport.<sup>5-9</sup> Yet, none have comprehensively reviewed current methods specifically for quantifying heading in adult football, considering gender and various moderating factors to understand the forces that occur in heading in football and how (nature) often they occur (frequency). Therefore, the primary purpose of this systematic review was to synthesise available evidence on methods to quantify heading in football and to summarise the technology, approaches and outcomes from practice, game and laboratory-based scenarios. This may help determine optimal measurement techniques for acceleration, force, nature and frequency of heading in football.

### Aim

This systematic review aimed to evaluate existing literature on (a) the measurement of acceleration, force, nature and frequency of heading in adult football players (male and female) during practice, game or laboratory-based scenarios; and (b) the role of moderating variables in influencing these measures. These variables include technical categorisation (such as header type, approach, preceding event and contact location), ball properties, playing position, level of play and gender. The goal is to enhance the understanding of how these factors affect head impact thresholds in football.

### METHODS

This study was conducted in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)<sup>10</sup> and implemented PRISMA in Exercise, Rehabilitation, Sport medicine and Sports science (PERSiST) guidance.<sup>11</sup> The review was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO) on 1 April 2021 under the identifier CRD42021249268. Eligible studies met the inclusion criteria presented in table 1. We defined 'elite' participation in professional football according to competitive

playing level from an international or national perspective.<sup>12</sup> For the synthesis, the quantification of heading in football included any method or combination of the following measures: heading frequency (how often heading takes place), linear/rotational acceleration (direction of the header), force (amount of force associated with the header) and nature (type of header or event preceding the header taking place).

### Literature search strategy

Initial searches were conducted in April 2021, repeated in February 2023 and May 2024 by the principal investigator (JA) to identify peer-reviewed articles in English published between 1 January 2000 and 31 May 2024. A comprehensive and systematic search was performed using the databases Ovid MEDLINE, ScienceDirect, SPORTDiscus, CINAHL, Web of Science, Scopus and ProQuest. Boolean operators 'OR' and 'AND' were applied to construct the final search phrases for keywords and MeSH/Subject Headings (online supplemental file 1). Citation and manual searches were then performed to identify additional applicable articles. Level 1 evidence, as defined by the Oxford Centre for Evidence-Based Medicine (OCEBM),<sup>13</sup> was prioritised.

### Study selection

Reviewer 1 (JA) and 2 (DR) independently performed the initial title and abstract screening. Studies meeting the search criteria at this stage were selected for the full-text review. Duplicates and studies that were out of scope were excluded. If a decision could not be made based on the title or abstract, the study proceeded to the full text review. Full-text articles that met the eligibility criteria were independently reviewed. Any discrepancies between the two reviewers were resolved in consultation with a third reviewer (MG). All records were managed using Endnote X21 (Clarivate Analytics, USA).

### Data extraction

Reviewer 1 (JA) extracted data from each study, focusing on participant demographics, methodological details and study

**Table 1** Study inclusion and exclusion criteria

Code	Inclusion criteria	Code	Exclusion criteria
1	Original research articles.	1	Reviews, surveys, magazines, periodicals, editorials, conference AND/OR abstracts, opinion pieces, non-peer reviewed text, non-academic text or white papers.
2	Football / Soccer or Field-Based Sports where intentional or unintentional head contact with the ball may be measured.	2	Non-football / soccer sports where heading is not considered a skill* of the game or where comparison to other sports is included.
3	Intentional heading of a football, whether subjectively or objectively measured, including aspects such as acceleration, force, nature and occurrence.	3	No measures of heading were reported (acceleration, force, nature and occurrence).
4	Participants aged $\geq 18$ years or the mean age of participants is $\geq 18$ years.	4	Mean age being $< 18$ years or age is not clearly reported to determine mean age of the population reported.
5	Male and/or female participants.	5	Full text not accessible or not in English.
6	Full text accessible and in English.	6	Studies where the quantification of football (soccer) heading is not the main outcome or purpose.‡
7	Data representing training, match play or laboratory-based studies.†	7	Laboratory-based studies using non-human methods only, such as anthropomorphic testing devices or MADYMO ellipsoid human body models without subsets of human participants, and / or the impact did not replicate heading characteristics.§
8	Competitive able-bodied football (soccer) players.		

\*For example, 'American Football', 'Australian Football' or 'Aussie Rules Football'.

†For example, biomechanical reconstruction using artificial head / neck or MADYMO modelling is solely used. For clarity, laboratory-based studies refer to investigations where data was not captured in a real-world 'on pitch' (field-based) training or game scenario. Field-based studies represent any data collection in a training / game scenario 'on-pitch'.

‡For example, if cognitive function, concussive symptoms or neurological assessment are otherwise part of the measured outcomes.

§For example, studies which use a force platform application to quantify impact translating into 'heading' were excluded, or studies which did not demonstrate purposeful heading technique.

characteristics using a custom-made Microsoft Excel (Microsoft Corporation) spreadsheet. Reviewer 2 (DR) independently cross-checked all extracted data for accuracy across all included papers. Any discrepancies were discussed between reviewers and, if necessary, a third independent reviewer to reach consensus. Where data was unavailable from the study's results, the authors were contacted by email. The extracted information included participant characteristics, study design, level of evidence, level of play and environment (online supplemental table 1).

### Quality assessment

Reviewer 1 (JA) and reviewer 2 (DA) independently conducted risk of bias through quality assessment of all included papers using validated tools relevant to the study type.<sup>14–16</sup> Based on search strategy and inclusion criteria (human vs simulation model), the articles eligible for bias and appraisal were divided into two categories: (1) studies that involve human participants and (2) studies that do not involve humans and of which data are modelled through mathematical reconstructions / simulation models. Separate risk of bias/quality assessment tools were therefore applied to each category accordingly (online supplemental file 1). For studies involving human participants ( $n=29$ ),<sup>14 17–43</sup> the Quality Assessment Tool for Quantitative Studies (EPHPP) was used, which evaluates six key domains: selection bias, study design, confounders, blinding, data collection methods and withdrawals/dropouts.<sup>14</sup> The tool is a valid and reliable measure for assessing the methodological quality of non-experimental study designs (online supplemental file 1).<sup>14</sup> For studies involving biomechanical or mathematical reconstructions ( $n=3$ ),<sup>44–46</sup> a different quality review was applied to reflect the methodologies of these study types (online supplemental file 1)<sup>15 16</sup> and adapted by removing two questions not applicable to the current systematic reviews research aims.

To ensure consistency across the two rating tools, each question within the critical appraisal for studies in category 2 was rated 0, 1 or 2, independently by both reviewers (JA and DR), and a consensus score was agreed on for each domain.<sup>15</sup> A scored checklist provided a measure of the standard of work and an overall percentage score, with an 80% threshold correlated to 'strong' content quality.<sup>15</sup> Any disagreements were resolved by consensus, with a third reviewer providing the deciding vote if necessary. To ensure robustness of findings, a sensitivity analysis was conducted through exclusion of studies rated as 'weak' in the Quality Assessment Tool for Quantitative Studies tool. The remaining studies, rated as moderate, demonstrated consistent findings supporting the strength of our conclusions.

### Statistical analysis

For the primary analysis, studies were categorised into four domains: acceleration, force, nature and frequency. Due to significant heterogeneity arising from variations in sample size, statistical methods, study design, outcomes measures and heading quantification methods, a meta-analysis was not feasible. Consequently, a descriptive quantitative analysis was provided for each study.

### Evidence synthesis

Descriptive data on the acceleration, force, nature and frequency of heading in adult football were synthesised, considering moderating variables outlined in the study's objectives. Data were presented in tabular format and qualitatively analysed.

### Equality, diversity and inclusion statement

Our research and author team comprised one woman and five men, all with extensive post-doctoral experience in the field. Due to limited translation resources, our search was restricted to English-language studies. Eligible studies were predominantly from Canada, the United States and Europe. Participants included both women and men aged 18 to 27. We acknowledge that the eligibility criteria exclude younger age groups, which limits the generalisability of our results to the youth population.

## RESULTS

### Study selection characteristics

A systematic search yielded 12863 records (figure 1). After removing duplicates and excluding articles based on title and abstract criteria, 167 full-text articles were screened. This screening process identified 20 eligible studies, with an additional 12 found through citation and manual searching, resulting in a total of 32 studies included in the review.<sup>1 4 17–46</sup> Online supplemental table 1 presents characteristics of the eligible studies including participants, level of play, environment and methodological design. Instrumentation for measuring acceleration, force, nature and frequency for included studies is presented in online supplemental table 2 with further reference from available literature in online supplemental file 2.

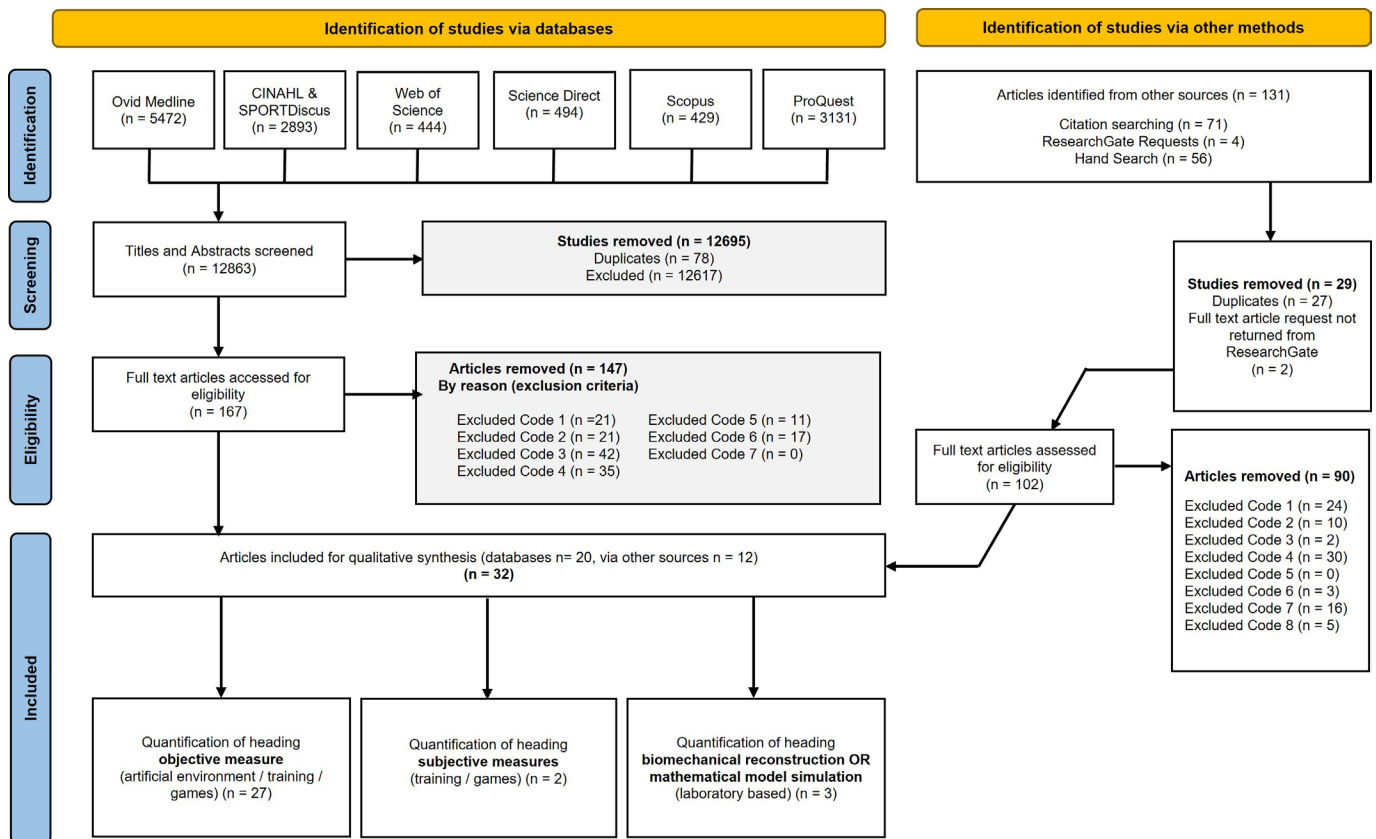
### Acceleration and Force

The most measured variables were peak linear acceleration (PLA), peak rotational acceleration (PRA)/peak angular acceleration (PAA)/rotational velocity (RV), collected simultaneously in 18 studies.<sup>1 18 20 24–26 28 30 32 34–40 44 45</sup> Other studies solely report PLA,<sup>17 22</sup> or peak impact power (W), impact force (N), and impulse value (N·s).<sup>4 36–38 46</sup> Three studies considered PLA and PRA data uniquely quantifying numerical reconstructions and human subjects.<sup>36–38</sup> Two biomechanical reconstruction studies used an anthropomorphic testing head (ATD) to quantify PLA and PRA.<sup>44 45</sup> The xPatch system (Biosystems, Seattle, WA) was the most frequently reported device.<sup>24 27 30 32 34 35</sup> Further details of accelerometry device placement alongside acceleration thresholds and sampling frequencies within applicable studies are reported in online supplemental table 2.

The highest accelerations were associated with headers from goal kicks.<sup>18</sup> In uncontrolled environments,<sup>18 20 24 26 30 34 35</sup> linear acceleration data tended to be lower in some studies that used artificially induced headers,<sup>17</sup> although not universally.<sup>22 31 40</sup> Some studies provided insights by comparing acceleration data between practice and games,<sup>20 25 26 28 30 34 35</sup> or game-halves.<sup>30</sup>

### Frequency

Frequency capture was represented through accelerometry,<sup>18 20 28 30 32 35</sup> coded video/camera analysis/footage,<sup>21 23 42 43</sup> time-synchronised video combined with acceleration<sup>24–27 34 39</sup> or a standardised protocol questionnaire.<sup>42</sup> One study captured data through Opta Sports in an elite population.<sup>41</sup> Three studies reported heading frequency subjectively through retrospective HeadCount Daily/2w,<sup>19 29</sup> or Soccer Heads-Up Checklist (SHUC),<sup>33</sup> with the latter simultaneously verifying headers through video analysis.<sup>33</sup> Heading frequency differed between playing positions,<sup>21 23 36 41 43 45</sup> yet verification of header frequency by type, strategic scenario, preceding event or exclusion of heading impact was the exception rather than the norm (online supplemental table 2). Incident rate of head impact exposures differed between genders and objective vs subjective measures<sup>19 32–35</sup> (online supplemental table 2).



**Figure 1** Preferred Reporting Items for Systematic Reviews (and Meta-Analyses) flow diagram of the selection process for studies included.

Typically, studies reported lower impacts in games compared with practices,<sup>25 26 30 35</sup> except for two studies,<sup>28 34</sup> where heading drills were not a part of in-season training. The highest frequency of heading per match overall was reported for the English Championship, though most data from European clubs pertained to the English Premier League.<sup>41</sup> Further analyses of heading frequency by specific subcategories in elite male and female populations<sup>21 23 43</sup> are identified in online supplemental table 2.

### Nature

Most studies reported various aspects of the nature of heading.<sup>1 4 17 18 20-40 42-46</sup> Typically, studies reported this as either a preceding event, header approach, body stance, ball delivery method, location of ball impact or type of header, individually or combined (online supplemental table 3). Some studies reported the heading nature alongside acceleration,<sup>1 17 18 20 22 31 44 45</sup> peak impact force<sup>4</sup> or frequency data<sup>21 23 27</sup> in uncontrolled scenarios. Other studies combined heading nature aspects such as playing position, ball delivery, player stance/posture, contact scenario and session type with acceleration and frequency data (online supplemental table 3).<sup>24-26 28 32 34 35 39</sup> The interpretation, reporting and other contextual factors influencing 'heading nature' however, varied between studies, limiting direct comparison of data.

### Moderation variables (Ball properties)

Ball properties were reported sporadically and inconsistently,<sup>1 4 17 19 22 31 37 38 40 45 46</sup> typically conducted in laboratory settings or artificial environment simulations.<sup>1 4 17 19 22 36 37 40 45 46</sup> (online supplemental table 2) The ball pressures used were often below those recommended by Fédération Internationale de

Football Association (FIFA) regulations, and other pressures were not thoroughly explored, with contact limited to a single location on the head.<sup>44</sup> Some studies aimed to standardise ball properties and considered multiple variables.<sup>1 22 31 40</sup> Although in many cases, information on ball type, speed, inflation or projection was not considered as moderating factors for heading response or was explored minimally.<sup>1 4 22 40</sup> It is important to note that comparing ball properties was often not the primary focus of those studies.

### Quality assessment

The highest risk of bias was noted in the study design and withdrawal/dropout categories, while confounding factors received strong ratings across most studies involving human participants.<sup>1 4 17-20 22-37 39 45</sup> Quality assessment for mathematical model studies<sup>21 38 44</sup> differed, yielding an overall percentage score based on 16 categories (online supplemental table 1). Those studies scored from 77% (moderate) to 80% (strong) for overall quality rating (online supplemental table 1). The lowest scoring categories were study design, followed by statistical methods of reporting. Comparing quality between the methodological styles is challenging, though the latter achieved higher quality ratings despite offering limited real-world context.

### DISCUSSION

This systematic review is the first to synthesise existing evidence on the measurement of acceleration, force, nature and frequency of heading in adult football during practice, games and laboratory investigations. Previous reviews have either focused on neurological responses or failed to report how heading is quantified. This review reports quantification methods and outcomes across the four domains; however, studies are limited by design,

methodological differences, standard of play, population, technology, analysis and the consideration of moderating variables, preventing the establishment of a standardised approach of heading in football. Inconsistent terminology was a common issue, and no study considered all four domains collectively.

Technology was used to quantify acceleration or force during heading impacts often suffered from limitations in validity, reliability, accuracy or usability in uncontrolled situations. Furthermore, none of the studies investigating the quantification of acceleration or force were representative of an elite adult football population. Differences in acceleration during heading were noted between genders, playing position, type of header, approaches and preceding events, and were influenced by ball properties and neck strength.

The results demonstrate gaps in knowledge regarding the optimal quantification of heading in adult football populations, hindering the determination of accurate thresholds for acceleration, force, nature and frequency measures during uncontrolled practice and game situations. This study highlights the need to standardise heading quantification in professional football through future investigations by using contemporary technology that accurately captures the nature, acceleration, force and frequency of heading simultaneously.

### Predominant measures of heading

Acceleration, nature and frequency were the predominant measures of heading reported in the eligible studies. Accelerometry commonly quantified both linear and rotational acceleration; however, challenges in identifying standardised approaches were evident due to the wide range of technologies, with upwards of fourteen different devices and varying metrics or protocols reported.

Typically, a threshold of 10 g was applied for linear acceleration data capture,<sup>18 24 28 30 32 34 35 45</sup> justified by the notion that accelerations below this level are typical activities of daily living.<sup>47</sup> However, lower operational ranges from 5 g to 8 g were reported.<sup>17 20 25–27 39</sup> Data processing filters varied across studies, often for the same device,<sup>27 30 34 35</sup> and comparing rotational acceleration proved problematic due to the variability in the SI units of measurements reported,<sup>1 18 20 24–26 30–32 34–39 44 45</sup> which inhibits consensus on standardising acceleration data capture.

The range of technology used to quantify acceleration (linear and/or rotational) across studies provides one of the greatest challenges in determining the most contemporary and accurate way to measure heading in football, with upwards of fourteen different devices used for quantifying accelerometry responses to heading alone. Headbands, skin patches and instrumented mouthguards (iMGs) fitted with accelerometers were used in both uncontrolled and laboratory simulations. Not all investigations acknowledged the reliability, validity or measurement errors reported in other studies.<sup>18 34 35 48</sup> For instance, skin patch and headband were noted for overpredicting peak head kinematics compared with iMGs,<sup>25</sup> posing issues such as unwarranted interference, sensor displacement and large errors<sup>7 34</sup> during competitive football matches, resulting in erroneous data. Consequently, these devices offer limited applicability for the professional game. The use of iMGs to quantify head impacts or acceleration events in sports has become more prevalent.<sup>5 7 49 50</sup> Several studies in the review agreed that iMGs provide an accurate, valid and reliable measure of acceleration during heading.<sup>22 25 39 40</sup> This is consistent with findings from recent research exploring the use of iMGs for quantifying impacts in rugby league.<sup>51</sup> Nonetheless, a recent opinion piece highlighted the technical limitations of

iMGs, such as the potential for false positives and false negatives when measuring head acceleration events. This suggests the need for developing post-processing algorithms and using video verification to mitigate underestimations.<sup>9</sup>

In the studies reviewed, only the frequency (and nature) of heading in elite professional football populations was considered.<sup>21 23 41 43</sup> Thus, to the authors' knowledge, acceleration (linear/rotational) data for this level of play to date remains unreported. Although many studies in the review convey frequency data, it is difficult to infer or compare findings to broader populations. Furthermore, studies often report overall heading impacts rather than differentiating by the intentional nature of heading a ball. Objective measures of frequency are typically reported alongside acceleration measures,<sup>18 20 24–26 28 30 32 34 35 39</sup> while others verify the nature of the heading through video analysis<sup>21 23 42 43</sup> or Opta Sports analytics.<sup>41</sup>

Though subjective frequency methods (HeadCount Daily/2w) may be considered consistent, reliable and valid for capturing heading exposure in adult amateur footballers,<sup>19 29</sup> their transferability to other levels of play, however, is limited and may not precisely quantify the number of headers a player performs.<sup>19 29</sup> Furthermore, neither study considered positional demands or context of play.<sup>19 29</sup> In professional football, analytical data provide accurate coding of preceding header events, header types and other outcomes related to overall heading frequency,<sup>52</sup> surpassing the accuracy of subjective measures (HeadCount). Nonetheless, in lower football leagues, this may be a useful, low-cost approach for measuring subjective header frequency, sensitive to various contextual factors, such as coach or tactical demands unique to each club. Further investigations are required to determine its relevance and necessity.

Often, frequency data in studies combines all head impacts without differentiating between specific scenarios, making it difficult to determine if the reported frequency truly represents heading in football. Studies that separate frequency data by scenario and combine it with the nature of heading characteristics often find significant differences in head impact exposure, particularly between playing positions. Defenders typically experience the most headers, followed by midfielders and forwards. Conversely, in the elite women's game, strikers perform significantly more contested headers than other positions.<sup>21</sup>

When data are categorised by moderating variables such as practice vs game, gender, playing position, and nature of heading, reaching a consensus on frequency is limited due to methodological, device and protocol differences, the small number of studies, level of play and low sample sizes. Additionally, frequency data may be influenced by club ethos, coaching philosophies and playing style (offence/defence/transitional), as acknowledged by some studies in this review.<sup>28 30 34 35</sup> Frequency per game half and the potential influence of fatigue on heading frequency cannot be established from the studies reviewed.

The nature of heading was inconsistently reported across studies investigating this as an outcome of heading quantification (online supplemental eTable 3). This makes it difficult to establish an initial agreement on predominant header types, approaches, ball delivery methods or preceding events across practices and games. The challenge is further compounded by varying playing standards, gender disparities and methodological differences across studies. When studies report heading frequency, they often group all types of impact together, failing to differentiate 'ball-to-head' categories.<sup>32 34 35</sup> As a result, our understanding of accurate heading quantification in the modern game, considering acceleration, frequency or force response, remains limited.

Nevertheless, Kenny *et al*<sup>25</sup> provide a comprehensive analysis of heading nature, combining accelerometry and frequency of data with video analysis and iMGs. They found a higher frequency of heading in training, with notable positional and ball delivery differences and greater force exposure for PRA, yet did not compare these frequencies against PLA. Importantly, they highlighted the failure of the mouthguards to capture 206 headers identified by video analysis. This study, limited to a female collegiate athlete population over one season and impacted by COVID-19 restrictions, underscores the variances in categorising heading nature. Given these methodological differences, determining which heading type, approach or preceding event results in greater acceleration response is challenging.

The inclusion of both laboratory and field-based studies was thought to be critical as laboratory methodologies offer, in contrast, a controlled environment that may provide insight into precise heading mechanisms under standardised conditions for interpretation. Alternatively, field-based investigations offer more ecological validity, accounting for the complex interplay and demands of the sport, not replicable in a laboratory setting. For example, strategic scenarios representing different preceding events of heading are difficult to perform when quantified by an ATD<sup>44 45</sup> or in an artificial throw-in laboratory-based scenario.<sup>1 4 22 31 40 44 45</sup> Alternatively, four studies conducted in an uncontrolled elite context<sup>21 23 41 43</sup> provide the most contemporary examples, extracting frequency data in conjunction with nature and categorising it across several heading characteristics. These findings collectively demonstrate an evolutionary progression in understanding heading nature and when reporting heading frequency data, suggesting that factors like the level of play, field location and match score may influence the characteristics of heading in the professional game.

With the tactical and physical demands of future games evolving,<sup>53</sup> accurate categorisation and appropriate sub-categorisation of heading nature in future studies are crucial for establishing coherent and consistent reporting. Consequently, the use of multi-camera video analysis is considered essential for defining the nature of heading.<sup>21 23 41 43</sup> There is a need for simultaneous real-time capture of heading nature along with acceleration, force and frequency data.

### Moderating variables on heading response

Previous literature, outside the scope of the current review, acknowledges advancements in football design, including consistency, shape and durability over several decades.<sup>54</sup> Equally important to the evolving science of ball design on performance is the comprehensive evaluation of modern football properties on force transmission during heading. Studies have investigated how footballs behave by manipulating ball speed,<sup>4 31 36 45</sup> or by collectively considering speed, pressure and inflation.<sup>44</sup> The latter suggests that PLA and PRA decrease when balls are launched at lower velocities, regardless of inflation pressure.<sup>44</sup> Authors indicate that at higher levels of competition, where greater kick velocities are common, players may sustain greater accelerative magnitudes during ball-to-head contacts.<sup>44</sup> However, caution is needed in interpreting these findings as the definition of 'highest' competition levels may not be comparable to elite standards.

Interestingly, reductions in ball inflation were found to have the greatest impact on PLA and PRA responses, although this was quantified using an ATD mannequin head and neck, which may not adequately represent on-field ball-to-head impacts. Consequently, it is challenging to obtain a true representation of these variables on the heading measures through reconstruction, as

competitive game situations, player involvement and functional movement may significantly confound measured responses. Similarly, studies involving human initiation of ball throwing are prone to standardisation errors compared with mechanical ball launchers, although they may more accurately represent a heading attempt. Regardless, neither method fully replicates actual practice or match data. Collectively, no study has evidenced the effects of multiple ball properties at an elite level, across genders, positions or exposure types during uncontrolled situations where environmental conditions, ball wear, construction or types are considered on heading quantification responses.

Functional neck strength is considered a potential moderating variable and is reported by some studies,<sup>1 4 36–38 40</sup> often in conjunction with measures of acceleration<sup>1 36–38 40</sup> or peak impact force,<sup>4</sup> with most employing electromyography to capture muscle activity data in laboratory-based environments.<sup>1 4 36–38 40</sup> Differences in muscle activation<sup>4</sup> or the correlation between isometric neck strength and angular head acceleration during heading were quantified.<sup>1</sup> Findings suggest that symmetrical strength in neck flexors and extensors can reduce head acceleration in collegiate footballers. Alternatively, Tierney *et al*<sup>40</sup> reported no differences in neck muscle activity strategies (pre-activity/reactivity), although women exhibited lower isometric strength compared with men. Recent reports suggest that higher neck strength may lower head acceleration during purposeful heading in soccer.<sup>55</sup>

While the functional involvement of muscles may influence heading measures in football, this review cannot fully determine its impact, as it falls outside the scope of the intended research question. Further investigations in adult football populations are needed to explore the influences of muscular activity, strength and force through applied methodologies on heading measures, in addition to other previously mentioned confounding factors.

### Limitations of evidence

Previous reviews on the use of technology to quantify impacts in sports have identified a lack of consensus in methodological procedures across studies.<sup>6 8</sup> Our findings align with this and suggest that such inconsistency may hinder the determination of the most valid and appropriate measures of heading in football, affecting the consensus on acceleration, force, nature and frequency outputs during heading. Consequently, limitations were evident in the studies deemed eligible for inclusion in this review.

Many articles report combined data for men and women (39%); however, the gender distribution is often unequal. Furthermore, studies typically have low sample sizes and focus predominantly on women's collegiate soccer. Only four studies represented higher levels of play, including professional European football leagues and the English Championship,<sup>41</sup> FIFA Women's World Cup,<sup>21</sup> International competitions<sup>23</sup> and Professional German Leagues.<sup>43</sup> These studies did not consider kinematic measures with frequency and nature, which, while not part of their intended aims, limit the comprehensive analysis.

No studies considered the influence of playing style, coaching or tactics on heading quantification. The approaches to quantifying heading vary, with minimal studies capturing data in applied settings (ie, uncontrolled situations during practice or games). While laboratory-based reconstructions and mathematical models provide useful insights, they may not accurately reflect heading during competitive situations, thus failing to provide realistic resultant data despite offering initial guidance on the forces experienced by the head during heading in football.

Commonly, studies do not account for moderating factors such as ball properties, positional differences, type of header, multiple team observations or other confounding factors known to influence heading impact. This makes direct comparison across studies difficult. Most studies employ cross-sectional observational designs, with few representing longitudinal data over multiple seasons and/or squads. Studies that considered game data rarely broke down observations into game halves, with only two exceptions,<sup>28 34</sup> thereby neglecting the potential moderating effect of fatigue on heading type or frequency, a factor that could be of interest in future work.

Methodological differences in protocols complicate the transferability of findings across different demographics, level of play or heading natures. Further, differences in studies investigating frequency, whether through analytical or subjective approaches, raise questions about the accuracy of reported frequencies. The inconsistency in technology and reporting of units of measurement across studies is significant, with data often coming from technologies with limited or varied validity and reliability. Some studies acknowledge that this inconsistency may have resulted in significant measurement errors. Additionally, laboratory-based studies may not accurately replicate the conditions of heading in practice or competitive gameplay. Variances are not limited to hardware and include software, sampling and filtration methods, posing challenges for cross-study comparison.

### Limitations of the review process

This review is limited to articles in English language, potentially restricting the pool of eligible studies. Due to the high risk of bias, varying study designs, methodological differences and inconsistencies in capture thresholds and variables, no meta-analysis was performed. Conducting such an analysis would have been inappropriate given that this review aimed to synthesise current knowledge in four key areas related to the quantification of heading in adult football. Consequently, while general heterogeneity and inconsistencies between studies were acknowledged as limitations, statistical heterogeneity was not assessed.

Additionally, the breadth of the inclusion/exclusion criteria may have excluded studies that reported measures of heading yet did not focus primarily on this aspect. Further, it is important to note that many studies examining the acceleration, force, nature and occurrence of heading in youth populations were available; however, they were outside the scope of this review. Finally, the consideration of playing surface was not explored nor reported, and notably, in training where synthetic turf may be used, this may affect ball bounce height, impacting 'second headers' following a bounce, and may consequently influence the acceleration, force, nature and frequency of heading.

### Implications

Although significant advancements in wearable technology can quantify measures of acceleration, force and frequency, these technologies have not been extensively explored within adult elite football populations. Most studies in this review were limited by issues of validity, reliability, usability and minimal exposure during actual game play. Furthermore, inadequate reporting of data sampling, thresholds or filtration, along with inconsistencies in data generation processes, may affect the results obtained. Laboratory-based or model reconstructions of heading provide valuable insights, although they have limitations in understanding heading in uncontrolled, competitive game situations influenced by numerous factors. There is a scarcity of studies that quantify heading during actual game play, limiting

quantification of the extent to which factors like coaching philosophies, anatomical considerations, fatigue, game half or other players influence the frequency or nature of heading. Consequently, this affects the understanding of cumulative PAA/PRA measures and output values, which remain unknown across elite adult football populations.

### Future research

Currently, there is no standardised process to accurately quantify heading in elite adult football. Available evidence presents several methodological and technological limitations, preventing the determination of thresholds for acceleration, force or frequency from the studies reviewed. Nevertheless, there is a consensus on using video verification to determine heading nature and frequency, alongside accelerometry measures, to accurately track ball-to-head impacts during practice or games.

Associations between neck strength and acceleration values were acknowledged although require further investigation across ages and genders to determine their influence on acceleration thresholds. Notably, the defensive playing position reported the highest frequency of heading across both genders, and women showed higher linear acceleration values compared with men. These findings might suggest the need for strength and conditioning practices tailored to position and gender-specific demands. Further investigation is required to determine the influence of these practices on acceleration during various heading categorisations that are yet unknown. Furthermore, the influence of ball properties on heading responses, including ball velocity and mechanical properties, requires further study.

To accurately reflect contemporary football's performance characteristics and demands, optimal and standardised quantification methods of heading must be employed. Implementing valid and reliable technology to accurately measure heading kinematics in real football environments is crucial. Only then can future longitudinal studies accurately consider or predict potential links between force transmission, injury and causation.

### CONCLUSIONS

Thresholds that represent functional demands of modern football at an elite level are essential, and further study is necessary to establish them. This systematic review describes current perspectives on the measures of acceleration, force, nature and frequency of heading in adult football, informing the standardisation and accuracy of quantifying heading in football. Contemporary studies investigating heading in football often do not collectively consider all these parameters. Methodological differences between studies further complicate direct comparisons and the drawing of substantial conclusions about each heading measure. Nevertheless, variations in heading measures were consistently observed between genders, playing positions and several categories, representing the nature of heading, such as type, approach, intent and preceding events. The quantification of heading in uncontrolled scenarios using valid and reliable technology concurrently capturing ball-to-head impacts through video analytics should be investigated further to determine any relevant clinical thresholds for heading.

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