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Cognitive Effects of Heading in Professional Football: A Systematic Review

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ABSTRACT

Large cohort studies have reported that former professional football players have an increased risk of mortality from neurodegenerative disease. Due to emerging concerns regarding the safety of heading the technique is now banned for players under 12. The aim of this systematic review was to evaluate the association between heading exposure and cognitive function in professional football players. A search strategy was devised and entered into seven electronic databases: MEDLINE, Embase, Web of Science, PsycINFO, CENTRAL, SportDiscus and PEDro. The search identified 563 records. After screening records and applying the eligibility criteria, nine cross-sectional studies (n = 925) were included in the review, investigating 452 current and 473 former players (859 males, 66 females). Six studies (n = 595) reported evidence for an association between heading and impaired cognitive function, while three studies (n = 330) reported no association. Diverse cognitive domains were investigated, which might underline the disparity in these results. The association between heading and cognitive function in professional football appears likely but remains inconclusive. Methodological heterogeneity and variability in the presentation of results limits the conclusions drawn. Prospective longitudinal studies using standardised methods, and including females, are required to provide evidence to support or refute an association.

Introduction

Football, also known as soccer, is the world's most popular sport. It is played by over 265 million people [1] and enjoyed by five billion fans worldwide [2]. Football differs from other pitch-based team sports by the use of a player's head to redirect the ball, a technique known as heading. Since its emergence over 150 years ago, the technique has developed into an integral part of offensive and defensive play [3]. Studies have shown on average a player heads the ball between 6 and 12 times per match [4–7], and it has been estimated professional players could be exposed to over 50,000 headers throughout their career [8].

Previous research in football has focused on the effects of concussion [9–13]. While this is an important area of research, concussion usually arises due to uncontrollable collisions with other players and incidence in football is low at 0.004–2.44 concussions per 1,000 player-hours [14]. Studies have reported impaired neurological functional and microstructure changes after repetitive head impacts [15], leading to a growing interest in the effects of subconcussive impacts in sport [16–20]. The term 'subconcussive' has been used to describe head impacts that do not induce typical concussion symptoms [21, 22]. However, cortical dysfunction has been observed in athletes after subconcussive impacts, even in the absence of clinical symptoms [18]. Football players are regularly exposed to multiple subconcussive impacts, as a result of heading the ball, although the clinical significance of this remains unclear.

The most concerning evidence regarding the safety of football has emerged from large retrospective cohort studies conducted in Scotland [23] and Sweden [24], which both reported a significantly increased neurodegenerative disease mortality risk in former professional players compared to age, sex and socioeconomic status matched controls. Additionally, both studies observed an increased risk in outfield players and those with the longest careers [24, 25], indicating that risks are higher in those with the greatest heading exposure. If these findings are attributed to heading alone, estimates have predicted the yearly global economic burden of heading could be $2.1 billion [26], providing a real cause for concern.

Due to concerns over players' welfare, the Football Association (FA) has issued guidance limiting heading in training in professional [27] and youth football [28]. A recent trial banned heading in players under the age of 12, making the technique a punishable offence [29]. Subsequently, the FA has decided to phase out deliberate heading in grassroots youth football in players under age 12 over the next three seasons [30]. Amid concerns that heading could present a public health risk, researchers have not yet provided conclusive evidence to confirm whether use of this technique is indeed detrimental to players' neurological function in the long term.

Systematic literature reviews have previously attempted to study the association between heading and cognitive function among players of all ages and levels [3, 7, 31–33]. However, due to the high variability in age and experience in the study populations included, and the quality and heterogeneity of studies, existing reviews have concluded that there is no definitive evidence to prove an association. The inconclusive findings may have arisen due to the effects of heading in those with the highest exposure being masked by those who rarely head the ball, generating conflicting results.

Large scale observational studies have shown heading exposure increases with age in children's and youth football [34, 35]. It has also been reported that heading exposure is higher in adults than adolescents [36], with elite-level male players shown to have the greatest exposure [37]. If an association between heading and cognitive function is to be identified, it might be most likely observed in professional players who present the greatest heading exposure. A review focused only on professional football players could provide this insight. Therefore, the aim of this systematic review was to evaluate the association between heading exposure and cognitive function in current and former professional football players.

Materials and Methods

This systematic review conforms to PRISMA guidelines [38] and was conducted in line with the PERSiST [39] guidance (i. e. implementing Prisma in Exercise, Rehabilitation, Sport medicine and SporTs science). The protocol for this review was registered with PROSPERO (CRD42023404209) and can be assessed at https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42023404209 [40].

Information sources

The literature search was conducted using seven online databases: MEDLINE (OVID), Embase (OVID), Web of Science, PsycINFO (OVID), CENTRAL, SportDiscus (EBSCOhost) and PEDro. The final search was conducted on 5 April 2023. Two additional records that met the eligibility criteria were identified and were included in the review. One identified via handsearching, and one published after the final search date.

Eligibility criteria

The following inclusion criteria was set: (1) the study investigated heading in football; (2) cognitive function was quantitatively measured; (3) study participants were current or former adult professional football players; (4) all observational or experimental study types; (5) published in English.

The following exclusion criteria was set: (1) participant age, sex, and level of play were not described; (2) study participants were under the age of 18; (3) non-peer reviewed studies; (4) full-text manuscript not available; (5) systematic, narrative or scoping reviews; (6) non-human studies.

Search strategy

The search strategy consisted of a combination of Medical Subject Headings (MeSH) terms and keywords listed in titles or abstracts. Four search blocks were designed to include articles related to: (1) heading (2) professional football (3) cognitive function and similar neurological outcomes and not related to (4) American football. Search terms were separated using the 'OR' Boolean operator. The first, second and third search blocks were separated using the 'AND' Boolean operator. The fourth search block was separated using the 'NOT' Boolean operator. The MEDLINE (OVID) search strategy was translated for each database where possible. The full search strategies for each database are available (see Appendix A–G).

Selection process

Records identified from the literature search were exported to EndNote 20 (Clarivate, Philadelphia) alongside the two additional records. Duplicates were automatically collated and manually checked before removal. The title and abstracts of the remaining reports were screened by two reviewers independently and reports that were not deemed relevant were excluded. The full-text manuscripts for remaining records were retrieved. The remaining reports were assessed by two independent reviewers for eligibility by applying the inclusion and exclusion criteria. Reports that did not meet the criteria were excluded, and the reason for exclusion was reported. Two independent reviewers reviewed the full-text manuscripts of reports that met the eligibility criteria to determine their inclusion in the review. The list of studies to be included in the review was agreed by the two reviewers. A third reviewer was available to resolve potential discrepancies by a simple consensus.

Risk of bias assessment

The studies included were subject to a risk of bias assessment. The JBI Checklist for Analytical Cross-Sectional Studies was used to critically appraise each study [41], which is the preferred assessment tool for analytical cross-sectional studies [42]. As all studies were cross-sectional, they all underwent the same assessment. Two reviewers independently assessed each study with no conflicting scores. The risk assessment tool critiques studies in eight areas based on their methods, measurements, interpretations, and statistical analysis. Studies meeting 0–4 conditions were deemed low quality, 5–6 conditions were deemed moderate quality, and 7–8 conditions deemed high quality. Poor studies were to be excluded from the review. The results of the risk of bias assessment are available (see Appendix H).

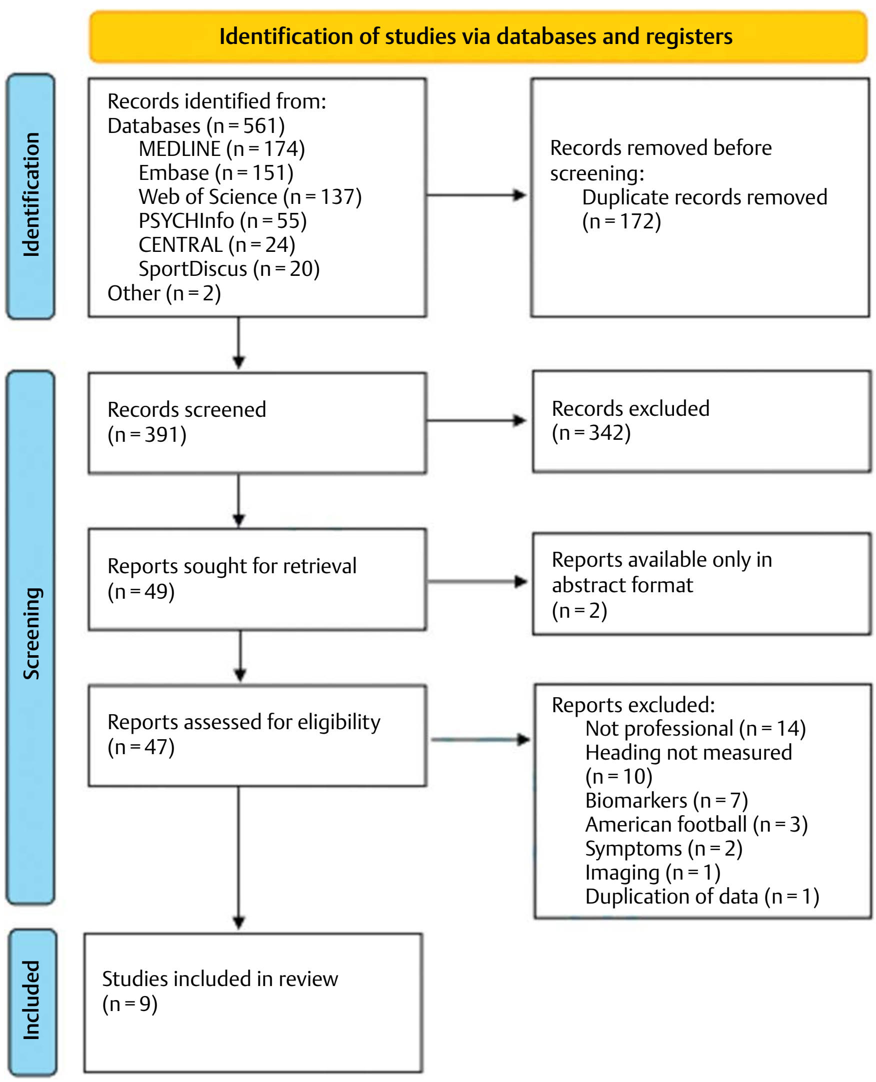
Results

Study selection

A total of 563 records were identified. The literature search identified 561 records alongside two studies identified outside of the search, and 172 (31 %) duplicates were removed. The titles and abstracts of the remaining 391 (69 %) records were screened. 342 (87 %) records were excluded after screening, as they were not relevant to the review topic. The full-text manuscripts of the remaining 49 (13 %) records were sought. Two (4 %) records were available only as conference abstracts and were therefore excluded. The eligibility of the remaining 47 (96 %) reports was assessed by applying the inclusion and exclusion criteria. Thirty-seven (79 %) reports did not meet the eligibility criteria and were excluded alongside a reason for their exclusion. Ten (21 %) reports met the criteria and were eligible for the review. However, two of these reports [43, 44] were identified as being from the same study. To prevent the duplication of data, the report [43] with the smaller sample size was excluded. Nine studies [8, 44–51] were selected to be included in the review. A flowchart illustrating the study selection process is shown in ▶ **Fig. 1**.

Study characteristics

Nine cross-sectional studies (n = 925) were included in the review. Six studies [8, 45–48, 51] (n = 595) reported evidence for an association



▶ **Fig. 1** PRISMA flowchart displaying study selection process [38].

▶ Table 1 Study characteristics of the nine studies included.

Study	Study design	Location	n	Sex	Age (mean ± SD)	Playing status	Heading exposure setting	Length of observation	Method of measuring heading exposure	Study quality grade
Bruno & Rutherford, 2022 [8]	C-S	UK	60	M	68 ± 10	Former	Matches and training	Professional Career	Self-reported estimate	High
Downs & Abwender, 2002 [45]	C-S	USA	6	M	42 ± 10	Former	Matches and training	Since youth	Heading exposure index	Moderate
Espahbodi et al., 2023 [46]	C-S	UK	326	M	63 ± 10	Former	Matches and training	Professional career	Self-reported estimate	High
Koerte et al., 2016 [44]	C-S	Germany	15	M	49 ± 5	Former	Matches and training	Lifetime	Self-reported estimate	Moderate
Matser et al., 1998 [47]	C-S	Netherlands	53	M	25 ± 4	Current	Matches only	1 season	Self-reported estimate	High
Matser et al., 2001 [48]	C-S	Netherlands	84	M	24*	Current	Matches only	1 season	Self-reported estimate	High
Prien et al., 2020 [51]	C-S	Germany and Netherlands	66	F	37 ± 5	Former	Matches and training	Lifetime	Self-reported frequency	High
Rodrigues et al., 2019 [49]	C-S	Brazil	44	M	25 ± 5	Current	Matches only	Professional career	Self-reported estimate with observed sample	High
Straume-Naesheim et al., 2005 [50]	C-S	Norway	271	M	26**	Current	Matches only	Since youth	Self-reported estimate with observed sample	High

C-S: cross-sectional; M: male; F: female; *median age, **standard deviation not provided.

between heading and impaired cognitive function, while three studies [44, 49, 50] (n = 330) reported no association. The studies were conducted in six countries and were published between 1998 and 2023. Study characteristics for each study are listed in ▶ **Table 1**.

Participant characteristics

The nine studies included 859 male and 66 female professional football players (mean age = 43). The studies investigated a mean sample size of 107.4 ± 113.5 football players. Four studies [47–50] reported data from current professional players (n = 452, mean age = 25) and five studies [8, 44–46, 51] from former professional players (n = 473, mean age = 59).

Study quality

The risk of bias assessment did not identify any studies of 'poor' quality. Seven studies [8, 46–51] were graded 'high' (n = 838) and two studies [44, 45] 'moderate' (n = 21). In the five studies with a control group, four studies [44, 45, 47, 51] compared against appropriately matched athletes with similar fitness levels (n = 140). One study [49] inappropriately compared football players to a control group consisting of guards and doormen (n = 44). All but one study [44] adjusted for confounding factors, including age, past head injuries, level of education, and alcohol consumption (n = 910).

Study methods

Various methods of measuring heading exposure were employed. Five studies [8, 44, 46–48] relied on estimated data collected from self-reported questionnaires (n = 538). A sample of matches were observed in two studies [49, 50] to confirm self-reported estimates aligned closely to the actual values (n = 315). One study [51] recorded heading frequency, and participants reported whether they were rare, moderate or frequent headers of the ball (n = 66). A heading exposure index based solely on the number of seasons played at various levels of competition provided estimates for cumulative heading exposure in one study [45] (n = 6).

Each study, apart from the two studies [47, 48] conducted in the Netherlands adopted a different method of cognitive testing. A paper or interview based cognitive test battery was used by five studies [8, 44, 46–48] (n = 538) and two studies [49, 50] (n = 315) used solely a computerized test battery to measure cognitive outcomes. Two studies [44, 45, 51] (n = 72) used a combination of paper or interview and computerized cognitive testing.

Presentation of results

The presentation of results differed greatly between studies due to the differences in methods of cognitive testing. ▶ **Table 2** displays the details of cognitive testing and results from each study.

Paper or interview based cognitive assessment

Out of the five studies that adopted solely a paper or interview based cognitive assessment, four studies [8, 46–48] reported an association and one study [44] did not. A Bayesian linear regression model reported that per 100,00 headers, Test Your Memory scores decreased by 3.2 points, providing evidence for a negative association between heading and the performance of subdomains of executive function [8]. A linear regression analysis was conducted by another study [46] that assessed the same subdomains: after ad-

▶ **Table 2** Cognitive testing details and results from studies included.

Study	Test (n)	Age (mean ± SD)	Playing status	Method of cognitive testing	Cognitive sub-domains tested	Main findings	Statistical results (95 % CI)
Bruno & Rutherford, 2022 [8]	60	68 ± 10	Former	Test Your Memory (TYM) self-administered paper-based cognitive test	Global executive function score (includes cognitive subdomains of: orientation, calculation, visuospatial ability, episodic memory, visual memory)	Negative correlation between estimated career headers and TYM scores.	Bayesian linear regression analysis: Per 100,000 headers TYM scores decrease by 3.2 points (1.6–5.3)
Downs & Abwender, 2002 [45]	6	42 ± 10	Former	Paper and interview based cognitive test battery: PASAT, FTT, WCST and computerized CPT	Sustained attention, motor speed, selective attention, cognitive flexibility	Significant negative correlation between estimated heading exposure and all five WCST test scores.	Age-partialled correlation coefficient between heading exposure and number of categories completed on WCST: − 0.51 ($p < 0.001$)
Espahbodi et al., 2023 [46]	326	63 ± 10	Former	Paper and interview based cognitive test battery: TICS-m, HVLT, VFA, TYM	Global executive function score, verbal memory, verbal fluency	Both match and training heading frequency were associated with a risk of cognitive impairment in later life and the associations were dose-dependent.	Linear regression coefficient for match heading frequency and test scores on TICS-m: − 1.09 ($p = 0.002$) and TYM: − 1.05 ($p = 0.003$)
Koerte et al., 2016 [44]	15	49 ± 5	Former	Paper and interview based cognitive test battery: TMT A and B, ROCF	Visual attention, task switching, visual memory	No significant correlation between cognitive or behavioral measures and lifetime estimates of heading. Football players scored worse than matched controls on delayed recall.	Football players performed worse on the long delay recall condition of the ROCF: mean T score 47.7 ± 14.7 versus 56.9 ± 8.8 ($p = 0.04$)
Matser et al., 1998 [47]	53	25 ± 4	Current	Paper and interview based cognitive test battery: RPM, WCST, PASAT, DST, TMT A and B, Stroop test, BWT, subtests of the WMS, CFT, 15-Word Learning Test, BFRT, Figure Detection Test, VFT, Puncture Test	Abstract reasoning, cognitive flexibility, sustained attention, visual perception, visual attention, task switching, inhibitory control, working memory, visual memory, episodic memory, verbal fluency, fine motor control	Significant negative correlation between heading exposure and short and long term memory CFT scores.	Adjusted regression coefficient for number of headers in a season and test scores on CFT short term memory: − 0.17 ($p = 0.048$) and CFT long term memory: − 0.19 ($p = 0.01$)
Matser et al., 2001 [48]	84	24*	Current	Paper and interview based cognitive test battery: RPM, WCST, PASAT, DST, TMT A and B, Stroop test, BWT, subtests of the WMS, CFT, 15-Word Learning Test, BFRT, Figure Detection Test, VFT, Puncture Test	Abstract reasoning, cognitive flexibility, sustained attention, visual perception, visual attention, task switching, inhibitory control, working memory, visual memory, episodic memory, verbal fluency, fine motor control	Estimated heading frequency observed was inversely associated to test scores assessing verbal and visual memory and focused attention.	Adjusted regression coefficients for impairment per 1,000 headers. CFT short term memory: − 3.24 ($p = 0.02$); CFT long term memory: − 3.34 ($p = 0.01$); TMT A 2.57 ($p = 0.048$); 15-Word Learning Test: − 3.76 ($p = 0.03$)
Prien et al., 2020 [51]	66	37 ± 5	Former	Paper and interview based test battery: CFT, DST, TMT A and B, PASAT and computerized CPT, FTT, SAT, SDC, Stroop Test, VBM, VMT	Motor speed, simple reaction time, complex attention, cognitive flexibility, processing speed, verbal memory, visual memory, verbal fluency, working memory, visual attention, task switching, sustained attention	Players with frequent heading exposure had significantly worse verbal memory scores than players with rare heading exposure.	Mean difference between frequent and rare headers verbal memory test scores compared to control group: − 9.166 ($p = 0.041$)
Rodrigues et al., 2019 [49]	44	25 ± 5	Current	Computerized cognitive test battery: Simple Reaction Time Test, Immediate Memory Test, Attention Test, Executive Functioning Tests (Number-letter-test, Two-back-test, Stroop-test), Delayed Memory Test	Simple reaction time, verbal memory, selective attention, task switching, working memory, inhibitory control, delayed memory	No significant difference in the cognitive test scores between football players with high and low levels of heading frequency. No correlation was identified between cognitive performance and estimated career heading frequency.	Correlation coefficients for estimated career heading exposure and test performance. Attention: 0.06 ($p = 0.665$); Memory: − 0.10 ($p = 0.521$)

▶ **Table 2** Continued.

Study	Test (n)	Age (mean ± SD)	Playing status	Method of cognitive testing	Cognitive sub-domains tested	Main findings	Statistical results (95 % CI)
Straume-Naesheim et al., 2005 [50]	271	26**	Current	Computerized cognitive test battery: Simple reaction time, choice reaction time, congruent reaction time, monitoring, one-back, matching, learning	Simple reaction time, decision making, sustained attention, divided attention, working memory	No association between estimated lifetime heading exposure or number of headers per match and cognitive test scores.	

PASAT: Paced Auditory Serial Addition Test; FTT: Finger Tapping Test; WCST: Wisconsin Card Sorting Test; CPT: Continuous Performance Test; TICS-m: Telephone Interview for Cognitive Status-modified; HVLT: Hopkins Verbal Learning Test; VFA: Verbal Fluency Assessment; TMT A and B: Trail Making Test A and B; ROCF: Rey Osterrieth Complex Figure; RPM: Raven Progressive Matrices; DST: Digit Symbol Test; BWT: Bourdon-Wiersma Test; WMS: Wechsler Memory Scale; CFT: Complex Figure Test; BFRT: Benton's Facial Recognition Task; VFT: Verbal Fluency Test; SAT: Shifting Attention Test; SDC: Symbol Digit Coding Test; VBM: Verbal Memory Test; VMT: Visual Memory Test; *median age; **standard deviation not provided.

justing for confounding factors, a significant correlation was reported showing that Test Your Memory performance decreased as heading exposure increased in both matches (β = − 1.05 [− 1.75, − 0.35]) and training (β = − 1.11 [− 1.77, − 0.41]). This study also assessed executive function using the modified Telephone Interview for Cognitive Status, and reported a correlation showing that increased heading exposure led to worse interview performance. Test scores were again significantly correlated with heading exposure in both matches (β = − 1.09 [− 1.77, − 0.41]) and training (β = − 0.95 [− 1.61, − 0.29]). The two studies [47, 48] utilizing the same 15 cognitive tests both reported that heading frequency was inversely associated with performance on cognitive tests assessing visual memory. One study [48] also reported a decline in both visual attention and episodic memory as the number of headers increased. In the one study [44] that reported no association, visual attention, task switching and visual memory test scores were not correlated with lifetime estimates of heading. However, in this same study football players displayed significantly worse delayed memory performance compared to control athletes.

Two studies [45, 51] used a combination of paper and interview based assessment and computerized assessment. One study [45] used a predominately paper and interview based assessment for subdomains of complex attention, perceptual motor function and executive function. They showed that football players with high heading exposures performed worse on the Wisconsin Card Sorting Test [45], reporting cognitive flexibility performance to be inversely correlated with heading frequency. The second study [51] conducted four paper based tests but did not report any difference in cognitive performance assessed by paper or interview based tests between frequent and rare headers of the ball.

Paper or interview-based testing was conducted by seven studies. Five studies reported an association between at least one of subdomain of cognitive function and heading. All five of these studies conducted linear regression analysis and reported heading exposure and cognitive test performance to be inversely correlated in at least one subdomain [8, 45–48].

Computerized cognitive assessment

The two studies [49, 50] that used only computerized cognitive assessment reported no association between heading and cognitive performance on all 14 computerized cognitive tests. One of these studies reported reaction times but not commission errors [50]. However, both studies analyzed current players with a mean participant age of 26 years. One study [49] reported no correlation between heading exposure and test performance assessing subdomains of executive function, memory and complex attention. The other study [50] reported no mean difference between players with high and low heading exposure in seven subtasks. Both studies [49, 50] observed no association between simple reaction time or working memory test scores and heading.

In the two studies [45, 51] that used a combined method of cognitive assessment, one study [45] only used the computerized Continuous Performance Test to assess selective attention and reported a significant correlation showing CPT test performance to worsen as heading exposure index scores increased. The second study [51] used seven computerized tests to assess seven different subdomains. They reported that participants who headed the ball more fre-

▶ **Table 3** Comparison of study and participant characteristics between studies showing an association between heading and cognitive function and studies not showing an association.

	Reporting association	Reporting no association	All studies
Study Characteristics	**Number of studies (n)**		
Studies included	6 (595)	3 (330)	9 (925)
Participant sex			
Male	5 (529)	3 (330)	8 (859)
Female	1 (66)	0	1 (66)
Playing status			
Current	2 (137)	2 (315)	4 (452)
Former	4 (458)	1 (15)	5 (473)
Location			
Europe	5 (589)	2 (286)	7 (875)
North America	1 (6)	0	1 (6)
South America	0	1 (44)	1 (44)
Study quality			
High	5 (589)	2 (315)	7 (904)
Moderate	1 (6)	1 (15)	2 (21)
Heading exposure setting			
Matches only	2 (137)	2 (315)	4 (452)
Matches and training	4 (458)	1 (15)	5 (473)
Length of observation			
1 season	2 (137)	0	2 (137)
Professional career	2 (386)	1 (44)	3 (430)
Since youth	1 (6)	1 (271)	2 (277)
Lifetime	1 (66)	1 (15)	2 (81)
Method of measuring heading exposure			
Self-reported estimate	4 (523)	1 (15)	5 (538)
Self-reported estimate with observed sample	0	2 (315)	2 (315)
Self-reported frequency	1 (66)	0	1 (66)
Heading exposure index	1 (6)	0	1 (6)
Method of measuring cognition			
Paper or interview based cognitive assessment	4 (523)	1 (15)	5 (538)
Computerized cognitive assessment	0	2 (315)	2 (315)
Paper or interview based and computerized cognitive assessment	2 (72)	0	2 (72)
Controls			
Appropriate	3 (125)	1 (15)	4 (140)
Inappropriate	0	1 (44)	1 (44)
NA	3 (470)	1 (271)	4 (741)
Adjusts for confounding factors			
Yes	6 (595)	2 (315)	8 (910)
No	0	1 (15)	1 (15)
Participant Characteristics	**Mean ± SD**		
Number of participants	99 ± 104.2	110 ± 114.5	103 ± 107.8
Mean group age	52	27	43

quently performed significantly worse on tests assessing verbal memory compared to players who rarely headed the ball.

In summary, two [45, 51] of the four studies that used a computerized assessment did report an association between at least one cognitive subdomain and heading, namely selective attention and verbal memory. However, the two studies [49, 50] that exclusively used computerized assessment both reported no association.

▶ **Table 4** Methods of cognitive testing and the cognitive domains reported to be associated or not associated with heading.

	Reporting association	**Reporting no association**
Cognitive Domains Tested	***Number of studies (n)***	
Complex Attention		
Paper or Interview Based Cognitive Assessment		
Sustained Attention	0	4 (209)**††[45, 47, 48, 51]
Visual Attention	1 (84)*[48]	3 (134)*††[44, 47, 51]
Computerized Cognitive Assessment		
Divided Attention	0	1 (271)†[50]
Selective Attention	1 (6)†[45]	1 (44)†[49]
Sustained Attention	0	2 (336)*†[50–51]
Global Executive Function		
Paper or Interview Based Cognitive Assessment		
Abstract Reasoning	0	2 (137)**[47–48]
Cognitive Flexibility	1 (6)†[45]	2 (137)**[47–48]
Inhibitory Control	0	2 (137)**[47–48]
Global Executive Function Score	2 (386)††[8, 46]	0
Task Switching	0	4 (218)**††[44, 47, 48, 51]
Working Memory	0	3 (203)**†[47, 48, 51]
Computerized Cognitive Assessment		
Decision Making	0	1 (271)*[50]
Cognitive Flexibility	0	1 (66)†[51]
Inhibitory Control	0	1 (44)*[49]
Task Switching	0	1 (44)*[49]
Working Memory	0	2 (315)**[49–50]
Language		
Paper or Interview Based Cognitive Assessment		
Verbal Fluency	0	4 (209)**††[45, 47, 48, 51]
Learning and Memory		
Paper or Interview Based Cognitive Assessment		
Episodic Memory	1 (84)*[48]	1 (53)*[47]
Verbal Memory	0	1 (6)†[45]
Visual Memory	2 (137)**[47–48]	1 (15)†[44]
Computerized Cognitive Assessment		
Delayed Memory	0	1 (44)*[49]
Verbal Memory	1 (66)†[51]	1 (44)*[49]
Visual Memory	0	1 (66)†[51]
Perceptual-motor Function		
Paper or Interview Based Cognitive Assessment		
Fine Motor Control	0	2 (137)**[47–48]
Visual Perception	0	2 (137)**[47–48]
Computerized Cognitive Assessment		
Motor Speed	0	2 (72)††[45, 51]
Processing Speed	0	1 (66)†[51]
Simple Reaction Time	0	3 (381)**†[49–51]

* study conducted on current players; † study conducted on former players.

Studies reporting no association vs. association

▶ **Table 3** compares the study and participant characteristics between studies reporting an association between heading and cognitive function [8, 45–48, 51] and studies reporting no association [44, 49, 50]. Eight studies investigated male players, with five studies [8, 45–48] reporting an association and three studies [44, 49, 50] reporting no association. The one study [51] investigating female players reported an association between heading and cognitive function.

Two [47, 48] of the four studies conducted on current professional players report an association, while two studies [49, 50] report no association. In the five studies conducted on former professional players, four studies [8, 45, 46, 51] report an association between heading and cognitive function and one study [44] reports no association. The mean participant age of football players in studies reporting no association was 27 years, while in studies reporting an association the mean age was 52 years.

Four [8, 45, 46, 51] of the seven studies that measured heading exposure over multiple seasons report an association, while three studies [44, 49, 50] report no association. However, the two studies [47, 48] that observed heading for only one season report an association.

Generally, the studies that report an association between heading and cognitive function investigate older, former professional players and use non-computerized methods of testing alongside self-reported estimates of heading. Conversely, the studies reporting no association broadly studied younger, current professional players using computerized testing and used observed samples to verify the accuracy of self-reported estimates.

Cognitive Domains

Each study assessed a variety of cognitive domains through the use of paper or interview based and computerized cognitive assessment. A comparison between the cognitive subdomains assessed between studies reporting and not reporting an association between heading and cognitive function is displayed in ▶ **Table 4**. The cognitive subdomains have been grouped into the domains: complex attention, global executive function, language, learning and memory, and perceptual-motor function, as defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) [52].

Complex attention

Complex attention was assessed by seven studies [44, 45, 47–51]. In the four studies [45, 47, 48, 51] using paper or interview based cognitive assessment sustained attention was not associated with heading. One study [48] did report an association between visual attention and heading but three studies [44, 47, 51] report no association.

Four studies [45, 49–51] assessed complex attention using a computerized cognitive assessment. One study [50] reported divided attention to not be associated with heading and two studies [50, 51] reported sustained attention to not be associated. Selective attention was shown to be associated with heading in one study [45]; however, another study [49] reported no association.

Visual attention and selective attention were the only subdomains reported to be associated with heading; however, all six subdomains of complex attention were reported not to be associated with heading in at least one study.

Global executive function

All nine studies assessed at least one subdomain of executive function, with seven studies [8, 44–48, 51] using a paper or interview based cognitive assessment. Abstract reasoning, cognitive flexibility, inhibitory control, task switching and working memory were all reported to not be associated with heading by two or more studies. However, one study [45] did show cognitive flexibility scores to be negatively correlated with heading frequency. Two studies [8, 46] reported a global executive function score, comprising of several executive function subdomains, that was also negatively correlated with heading frequency.

Computerized testing conducted in three studies [49–51] reported decision making, cognitive flexibility, inhibitory control, task switching and working memory were all not correlated to heading frequency.

In summary, global executive function score and cognitive flexibility were associated with heading, the other nine tested subdomains of executive function were not.

Language

Four studies [45, 47, 48, 51] assessed verbal fluency using a paper or interview based cognitive assessment and all reported that function of this subdomain was not associated with heading.

Learning and memory

Four studies assessed three subdomains of learning and memory using paper or interview based cognitive assessment. One study [45] reported verbal memory to not be associated with heading. Episodic memory performance was shown not to be correlated to heading frequency in one study [47] but in another study [48] was reported to be negatively correlated to heading frequency. Additionally, two studies [47, 48] reported that heading frequency was negatively correlated with visual memory performance; however, one study [45] reported no correlation.

Computerized cognitive assessments were conducted in two studies [49, 51]. One study [49] reported that both delayed and verbal memory were not associated with heading and another study [51] reported visual memory not to be associated with heading. However, the second study [51] did report that verbal memory performance was associated with heading.

In summary, there are conflicting findings with respect to episodic memory, visual memory, and verbal memory, as these subdomains were reported to either have an association in some studies, and no association in others.

Perceptual-motor function

Two subdomains of perceptual-motor function were assessed by two studies [47, 48] using paper or interview-based assessment. Both reported no association between fine motor control and visual perception and heading. Two studies [45, 51] assessed motor speed, one study [51] assessed processing speed, and three studies [49–51] assessed simple reaction time using a computerized cognitive assessment. All three subdomains were shown not to be associated with heading. In total, all five subdomains of perceptual-motor function tested were reported to not be associated with heading.

Discussion

This systematic review aimed to investigate the association between heading and cognitive function in professional football players. From the studies included in this review, six studies reported an association between heading and cognitive function, while three reported no association. Studies conducted on current professional players were equally as likely to report an association between heading and cognitive function as they were to not report an association. However, the majority of the studies conducted on former professional players reported an association between heading exposure and cognitive function. Of the studies that did report an association, the cognitive domains that appeared most likely to be affected were global executive function, complex attention and memory. This suggests that there may be specific domains of cognition that could be negatively associated with increased heading frequency in football players, and that these associations are more likely to present themselves in retired players.

Cognitive testing

Broadly, the subdomains that were reported to be associated with heading exposure included visual attention, selective attention, cognitive flexibility, episodic memory, visual memory, verbal memory and global executive function. However, the studies reviewed implemented a variety of test methods to assess similar aspects of cognitive function, including both paper or interview-based cognitive assessment and computerized assessments, making it challenging to compare study outcomes. These processes are largely directed by the prefrontal cortex, located beneath the forehead where players typically head the ball [53]. It remains to be understood whether sub-concussive impacts to this region could potentially be directly causing localized microtrauma leading to neurodegeneration.

The only two studies that utilized solely computerized tests reported no significant association between heading exposure and cognitive test performance. However, it should be noted that both studies only included young current players averaging 25 years of age. This is important to note as deficits to cognitive function caused by concussive and subconcussive impacts are typically observed in the long term due to a possible accelerated decline in cognitive function [18]. A ceiling effect in the younger players, further impacted by the low difficulty of some of the tasks that were implemented [54], could potentially also be masking any early evidence of possible impaired cognitive performance [55]. Furthermore, one of the studies [50] only reported analyses on reaction time measures of the tasks, not accuracy, and neither study reported commission errors. If heading exposure is to impact prefrontal cortex function, it would be plausible to expect an increase in commission errors on executive function tasks (such as early key presses on a simple reaction time task, and no-go errors on an inhibition or attention task) [56]. Further studies that implement computerized tasks should consider commission errors as an outcome measure and should investigate the effects of lifelong heading exposure on retired athletes.

Lifetime heading exposure and previous concussions were significantly correlated in the two studies that presented this data [48, 50]. Crucially, headers and concussions had differential and unrelated effects on cognitive domains [48], indicating that headers might induce neurocognitive changes that are different to those sustained during concussions. However, when interpreting the results, it is important to note that previous concussions sustained while playing football may influence reduced cognitive performance, which the studies did not control for.

Current vs. former professional players

Findings between current and former professional football players differed. Half of the studies conducted on current professional players reported an association between cognitive function and heading exposure. In contrast, four of the five studies conducted on former professional players concluded that heading was associated with cognitive outcomes. This could suggest that the detrimental effects of heading are more likely to present themselves in later life. It is possible that heading could be accelerating cognitive ageing however it is difficult to exclude the effects of concussions and player to player collisions, which are common in elite football and could contribute to a decline in function. Additionally, it is important to recognize that some players who perform well on cognitive tests may exhibit structural changes in the brain that may not manifest as cognitive impairment for many years to come. White matter microstructure alteration has been observed in both male and female amateur players under age 30 [57], which suggests that cognitive testing may not be best method to identify neurological changes in current players. Therefore, some cognitive tests implemented by studies in this review may not have been sensitive to specific structural changes that could have been occurring.

Two large cohort studies in Scotland [23] and Sweden [24] provide evidence to question the safety of heading the ball, and are the only studies to date to analyses thousands of former professional players. Football players were shown to have an increased risk of mortality [23] and development of neurodegenerative disease [24]. Although, the majority of players included in these studies played before the 1970s and are likely to have played with leather balls. These balls have been shown to increase in weight by up to 20 % in wet conditions [58] increasing head acceleration forces during heading. It is likely that in six of the studies included in this review [8, 44–48] the players studied played the majority of their professional careers in the 20th century, when balls were heavier. Interestingly, five of these six studies report an association between cognitive function and heading. The heavier balls may have contributed to the increased risk, although it is not known if the synthetic balls currently in use completely mitigate these effects.

In contrast to the evidence provided by these two large cohort studies, Vann Jones et al. reported that the prevalence of cognitive impairment among former professional players is not significantly different from the general population [59]. Despite our review raising concerns about former professional players, it is difficult to attribute the decline in function to heading specifically rather than an age-related decline in cognitive function or other possible confounding factors. Further longitudinal studies are needed to confirm a causal relationship between heading and cognitive decline in football players.

Female players

In this review, 93 % of the players investigated were male, making the findings mostly representative of male professional players. Only one study was conducted on retired female players, which reported a significant association between heading frequency and verbal memory performance. Female participation in football is rapidly rising with FIFA aiming to have over 60 million female players by 2026 [60] and incidence of heading in the female game being of a similar level to males [37]. Previous research has highlighted that rates of head injuries are higher in female players, which emphasizes the need to conduct more studies on female players and possible gender differences in such effects [13, 61, 62].

In line with this, Rubin et al. [57] investigated the effects of heading between male and female football players on white matter microstructure alteration, identifying a fivefold greater volume of affected white matter in females compared to males in response to similar exposure to heading throughout their careers. Together, these results suggest that females might be more susceptible to neurological damage following subconcussive head impacts, but more research is needed to corroborate this and identify potential mechanisms involved.

Measuring heading exposure

Eight of the nine studies measured heading exposure using self-reported estimates or frequencies, which have been described as an inaccurate method of measurement [33, 37]. Although there is a correlation between self-reported and actual values, footballers have been shown to overestimate their heading frequency [63, 64]. Self-reporting in other disciplines has also been reported as unreliable [65–67]. Samples of observed heading in two of the studies showed no significant difference between self-reported values and actual observed headers [49, 50], which suggests that estimated values may be reliable in certain populations. Self-reporting can reliably group participants into low and high heading exposure groups, but should not be used to measure individual exposure due to recall bias [64], which is particularly likely to arise in former professional players attempting to remember their heading history from potentially many decades ago. It is also important to consider the accuracy of self-reporting is likely to be lower in players suffering from cognitive impairment, potentially resulting in type I and II errors.

Limitations

The studies in this review display significant clinical diversity and methodological heterogeneity. The variability in study design, participant characteristics, and methods of measuring heading exposure and cognitive function, makes comparison between observations in different study populations challenging. Although the risk of bias assessment described all studies to be 'moderate' or 'high' quality, methodological issues were highlighted in all studies, such as with the reporting of heading frequency. Additionally, different cognitive tests and methods were adopted across studies. The papers commonly did not control for key confounding factors such as previous concussion history, education level, participation in other contact sports, and exposure to neurodegenerative disease risk factors. To reach more reliable conclusions, further studies could consider adopting a longitudinal design against matched control groups, quantifying heading exposure based on observed measures, target areas of cognitive function most likely to be affected by frontal impacts and obtain a more comprehensive history of player demographic information and other neurological risk factors.

Conclusion and future direction

This review provides some evidence for an association between heading and cognitive function in professional football, although a strong conclusion could not be drawn due to the high heterogeneity in methods implemented. These findings suggest that the decision to impose a ban on heading at youth level is well reasoned; however, it is unknown whether or not the benefits of this will be diminished when players subsequently start heading the ball.

Considering that studies looking at former professional players were more likely to report an association than those on current players, future studies should consider longitudinal monitoring of neurocognitive outcomes in athletes, with objective monitoring of heading exposure. The cognitive domains that appeared most likely to be affected included complex attention, executive function, and memory, and should therefore be considered in future testing.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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