Science and Medicine in Football

ISSN: 2473-3938 (Print) 2473-4446 (Online) Journal homepage: www.tandfonline.com/journals/rsmf20

A new match-heading index for male professional football players based on objective and video sources – SoccHealth

Hansjörg Baurecht , Jürgen Wellmann , Michael J. Stein , Michael F. Leitzmann , Mike Abroscheit , Claus Reinsberger , Werner Krutsch, Tim Meyer & Klaus Berger

To cite this article: Hansjörg Baurecht , Jürgen Wellmann , Michael J. Stein , Michael F. Leitzmann , Mike Abroscheit , Claus Reinsberger , Werner Krutsch, Tim Meyer & Klaus Berger (06 Sep 2026): A new match-heading index for male professional football players based on objective and video sources – SoccHealth, Science and Medicine in Football, DOI: 10.1080/24733938.2026.2727018

To link to this article: https://doi.org/10.1080/24733938.2026.2727018

SCIENCE AND MEDICINE IN FOOTBALL
https://doi.org/10.1080/24733938.2026.2727018

Routledge
Taylor & Francis Group

A new match-heading index for male professional football players based on objective and video sources – SoccHealth

Hansjörg Baurecht[a,b], Jürgen Wellmann[c], Michael J. Stein[a,d], Michael F. Leitzmann[a], Mike Abroscheit[e], Claus Reinsberger[f,g], Werner Krutsch[h], Tim Meyer[e] and Klaus Berger[c]

[a]Department of Epidemiology and Preventive Medicine, University of Regensburg Faculty of Medicine, Regensburg, Germany; [b]Department of Epidemiology and Preventive Medicine, Medical Sociology, University of Regensburg, Regensburg, Germany; [c]Institute of Epidemiology and Social Medicine, University of Münster, Münster, Germany; [d]Institute of Epidemiology, Helmholtz Zentrum München, German Research Center for Environmental Health (GmbH), Neuherberg, Germany; [e]Institute of Sports and Preventive Medicine, Saarland University, Saarbrücken, Germany; [f]Institute of Sports Medicine, Paderborn University, Paderborn, Germany; [g]Division of Sports Neurology & Neurosciences, Department of Neurology, Mass General Brigham, Boston, MA, USA; [h]Department of Trauma Surgery, University Medical Centre Regensburg, Regensburg, Germany

ABSTRACT

Repetitive heading of the ball is a distinctive feature of professional football (soccer) and has been discussed as a potential long-term risk factor for neurodegenerative disease. Epidemiologic investigation is limited by the absence of valid methods to quantify heading exposure across a player's career. To provide a tool for estimating the heading frequency in male professional football players for epidemiological studies where detailed career histories exist but sufficient individual heading exposure data are lacking. Detailed career histories of former male football players were combined with position-specific heading rates derived from two systematic video analyses spanning multiple decades and league levels in Germany. Season-specific heading rates were estimated using natural cubic splines by position, league level, seasons, and combined with playing time to calculate cumulative exposure. Heading rates varied substantially by position and changed markedly over time. In the absence of a gold standard, the plausibility of the match-heading index was evaluated in the SoccHealth project using negative control outcomes. The cumulative heading index showed no association with negative control outcomes (body mass index and handgrip strength), while expected age-related associations remained, which may be interpreted as consistent with the index's plausibility. We present a novel match-heading index that can be combined with objective career-history data to estimate cumulative career-long match-heading exposure in former male football players. By integrating objective video-based data with detailed career histories and accounting for temporal and positional variation, this approach substantially improves exposure assessment for future epidemiologic studies of long-term neurological outcomes in football players.

ARTICLE HISTORY
Accepted 22 August 2026

KEYWORDS
Football heading exposure; video analyses; cross-league data; long-term data; SoccHealth branch of the NAKO study

Introduction

Assessing exposures that are considered potential health hazards in professional sports poses substantial challenges. This is particularly true for contact sports such as football (soccer), where a wide range of approaches has been used to estimate exposure, among them self-reports by players, assessments by external observers, video analyses, and, more recently, wearable sensors (Beaudouin et al. 2020; Bruno and Rutherford 2022; Roe et al. 2024; Chilmeran et al. 2025). Each of these approaches has inherent limitations, especially when the aim is to quantify exposure over long periods of time (Beaudouin et al. 2020; Roe et al. 2024).

Football is unique among professionally played contact sports since it includes intentional heading the ball as an important and recurring component of the game. For several years, heading exposure over the course of a player's career – particularly during childhood and adolescence – has been discussed as a potential risk factor for neurodegenerative diseases, including dementia and chronic traumatic encephalopathy (CTE) (Mackay et al. 2019; Orhant et al. 2022; Ueda et al. 2023). A common feature of these conditions is their long latency period, with clinical manifestations often decades after the relevant exposures. Consequently, associations between heading exposure during an active playing career and later disease cannot be adequately examined in clinical or short-term studies but require long-term observational

CONTACT Hansjörg Baurecht hansjoerg.baurecht@klinik.uni-regensburg.de Department of Epidemiology and Preventive Medicine, University of Regensburg, Franz-Josef-Strauss-Allee 11, Regensburg 93053, Germany

Supplemental data for this article can be accessed online at https://doi.org/10.1080/24733938.2026.2727018

designs such as retrospective and prospective cohort studies or register-based analyses.

A central challenge in this context is the valid assessment of heading exposure across an entire professional career. Individual headers during matches or training sessions cannot be validly assessed by wearables, and direct observation or video-based counting is feasible only for limited time periods and selected competitions. While video analysis provides an objective measure of heading frequency, it is practically impossible to apply this approach continuously over all seasons, leagues, and matches of an individual player's career. Moreover, systematic information on heading frequency during training is largely unavailable, although training may contribute substantially to heading exposure over a professional career. Taken together, these limitations mean that most previous studies have relied on player self-reports to estimate heading frequency. However, self-reported lifetime exposures are highly susceptible to recall bias (Sandmo et al. 2022) particularly when exposures occurred many years or decades earlier.

The development of a robust index for heading frequency in football therefore must aim to minimize reliance on recall, capture long-term changes in playing style and game intensity, and account for key determinants of heading frequency, such as playing position. Tactical developments in professional football over recent decades have altered the speed, physicality, and aerial components of the game, with important implications for heading exposure.

Several heading exposure indices have been proposed in recent years. Most rely on self-reported heading frequencies (Rodrigues et al. 2019; Sandmo et al. 2022) sometimes combined with information on career duration or match counts to derive cumulative exposure estimates (Bruno and Rutherford 2022; Gallo et al. 2024). Other approaches have validated short-term self-reports against external observation, but only over brief time windows (Catenaccio et al. 2016). Only rarely has systematic video analysis been used (Beaudouin et al. 2020) and then typically for selected matches or seasons. As a result, existing indices remain vulnerable to exposure misclassification and are limited in their ability to reflect long-term temporal trends in heading frequency.

The aim of the present study was therefore to develop a quantitative match-heading frequency matrix for former professional football players that provides an estimate of time-varying match-heading frequency across an entire professional career. The approach integrates detailed career histories with position-specific, video-derived heading rates and explicitly incorporates temporal changes in match-heading frequency. In the absence of a gold standard for lifetime heading exposure, a secondary aim was to evaluate the plausibility of the derived match-heading index using negative control outcomes, i.e., those that, by definition, should not be associated with heading exposure.

Materials and methods

Data sources

Two independent video datasets were utilized to estimate average match-heading rates by playing position. The first dataset comprised a cross-sectional assessment of headers performed by players in all official matches of the four highest men's professional football leagues in Germany (1st to 4th league) during the 2017/18 season, stratified by playing position (Weber et al. 2023). For the second, longitudinal dataset, video material was obtained from restricted-access archive of the Deutsche Fußball Liga, which contains all official football matches (DFL Sportcast Media Portal 2023). It includes 15 randomly selected matches from the 1st Bundesliga per season and playing position at five-year intervals from the 1975/76 to 2005/06 season, corresponding to the active playing periods of most SoccHealth participants. To extend these estimates toward more recent years and bridge the gap to the cross-sectional dataset on the four leagues in 2017/18, additional matches from the 2009/10, 2013/14 and 2017/18 seasons were subjected to video analysis. All videos were analysed using standardised protocols by trained investigators, including one of the co-authors (MA). For the cross-sectional video dataset, the average number of headers per position and match (90 min) during the 2017/18 season was obtained. For the longitudinal video dataset, the number of headers was counted by one co-author in randomly selected games (90 min) for each playing position.

The German National Cohort (NAKO) is Germany's largest population-based prospective health study, including approximately 205,000 participants aged 20 to 75 years, who were recruited between 2014 and 2019 in 18 study centres representing urban, industrialized, and rural German regions. A detailed description of the study design and methodology has been given elsewhere (Peters et al. 2022). Briefly, participants were randomly selected from local population registries using an age- and sex-stratified sampling process, with intentional oversampling of individuals aged 40–69 years. The comprehensive baseline assessments were conducted at two levels of intensity (Level 1: on average 4 h, Level 2: 6 h) and included face-to-face interviews, questionnaires, diagnostic clinical examinations and functional measurements, and biosample collection (Schipf et al. 2020). All participants provided written

informed consent, and the study was approved by the relevant local ethics committees.

SoccHealth is a NAKO satellite project that used the NAKO infrastructure and expanded Level 2 examination program during the first NAKO follow-up phase (2019–2024). The project has been described in detail elsewhere (Berger et al. 2024) and assesses the health of former professional football players and includes advanced imaging and biomarker assessments. The present analyses were restricted to male former professional football players, as the exposure matrix – the average number of headers per match according to playing position and season – was derived from video material from men's professional leagues.

Individual professional career histories were assessed using two complementary approaches. First, former professional players completed a career-specific self-report questionnaire that included information on leagues and seasons played, primary playing position and its consistency over time, and major injury patterns. Second, publicly accessible online databases (www.kicker.de) and www.transfermarkt.de (Transfermarkt 2024) were used to extract objective career information. For each player, data on the number of seasons played, league level, number of matches, total playing time in minutes, and playing position were extracted, pseudonymized, and securely linked to the SoccHealth examination dataset via the NAKO transfer centre.

Statistical analyses

To harmonize information across datasets (NAKO SoccHealth, the Kicker/Transfermarkt databases, and video analyses), we mapped the various playing positions onto a uniform scheme of goalkeeper, centre-back, full-back, midfielder and striker. This mapping was agreed upon by domain experts within the study team and ensured consistent positional classification over time.

Heading rates in the 1st Bundesliga from the 1975/76 to 2017/18 seasons were modelled using a Poisson and negative-binomial regression model. The number of headers was specified as dependent variable, with the logarithm of the corresponding playing time as 'offset'. Using canonical log-link, the expected heading rate was modelled as a function of a natural cubic spline of the date of the match, the playing position as a categorical main effect, and the interaction of both as independent variables. Models with three and four knots were evaluated. A spline model with three knots provided a stable fit, while a model with four knots provided a closer fit and was retained for sensitivity analyses to assess the robustness of exposure estimates. The outcome of these models was the observed number of match-headers for a -given year (season) and player position.

Heading rates for seasons without direct video observations were estimated by interpolation. Estimates derived for the 1st Bundesliga were extrapolated to other leagues by applying empirically derived inter-league proportionality factors based on the 2017/18 cross-league video dataset. Expected cumulative heading frequency for each player was then calculated by combining position-specific heading rates derived from video analyses with individual career histories, including seasons played, league level, and playing time from the Transfermarkt database without relying on any player self-report data. Thus, the individual cumulative career-long match-heading index was calculated by summing, across all seasons, the products of the average heading rate (based on video data) for a given playing position and season and the player's corresponding playing time (Transfermarkt).

Associations between career-long match-heading index and outcomes were analysed using linear regression models for continuous outcomes adjusted for age at baseline. As negative control outcomes, we used body mass index (BMI) and handgrip strength, as we expected no associations with heading rate but a potential association with age at recruitment. Statistical analyses were performed in R (R Core Team 2024) utilizing the splines package, and SAS (SAS Software SAS Institute Inc 2023).

Results

Career details of the analysed 295 male SoccHealth participants (Supplementary Figure S1) are shown in Supplementary Table S1. The age at initiation of organized football in childhood differed little across participants, typically around 6 years. About two thirds of participants had played in both the 1st and 2nd Bundesliga during their careers. Concordance between self-reported career duration, measured as the number of seasons played, and information extracted from online databases was generally good, although a small number of players showed substantial discrepancies. (Supplementary Figure S2). Most participants reported a stable main playing position over their professional careers. The median reported time since end of career was 22 years (interquartile range: 16–29).

Although we detected overdispersion in the Poisson regression models used to estimate match-heading frequency, we did not switch to negative-binomial models because both approaches produced broadly similar fitted average profiles, except of strikers. For this position, the Poisson spline showed from the 2000s onwards

a tendency to deviate towards the cross-sectional data (4 headers per game) derived from all matches in the 2015 1st Bundesliga season. In contrast, the negative-binomial spline tended to align more closely with the longitudinal data (6–7 headers per game) based on five randomly selected matches (Figure 1, Supplementary Figure S1). Finally, we relied on visual inspection to assess model fit, which suggested that the Poisson models were adequate overall. Heading rates in the 1st Bundesliga varied significantly by playing position and changed markedly between 1975 and 2017. Goalkeepers rarely performed headers, whereas all outfield positions showed increasing heading frequencies from the 1970s through the 1990s (Figure 1). For centre-backs, midfielders, and strikers, heading rates peaked in the mid-to-late 2000s, followed by a modest decline in subsequent years. In contrast, full-backs showed a more continuous increase in heading frequency over the observed period. Differences between spline models were small, and alternative specifications produced comparable exposure estimates (Supplementary Figure S4). Temporal, positional, and league-specific patterns in heading rates are summarized graphically in Figures 1–3 and Supplementary Figures S4–S6.

We also observed considerable differences in heading rates during the 2017/18 season across the four highest leagues in Germany, except for goalkeepers (Figure 2). Among the first three professional German leagues, heading rates increased progressively from the 1st Bundesliga to the 3rd Bundesliga across all playing positions. Centre-backs exhibited the highest rates, followed by midfielders, full-backs, and strikers. Players in the semi-professional league performed fewer headers than professionals in the centre-back position, and slightly fewer in the full-back and striker positions. In contrast, midfielders in the semi-professional league showed higher heading rates compared to those in the 1st and 2nd Bundesliga (Figure 2).

Using the two video data sources described above, we extrapolated heading rates for seasons without direct video observations (Figure 3 and Supplementary Figure S4). Lower league curve shapes follow the spline fitting from the 1st Bundesliga data, their vertical positions are determined by cross-sectional rates across all leagues, depicted as diamonds (Figure 3, Supplementary Figure S5). Comparison of exposure indices derived from spline models with three and four knots revealed only minor differences (Supplementary Figure S6).

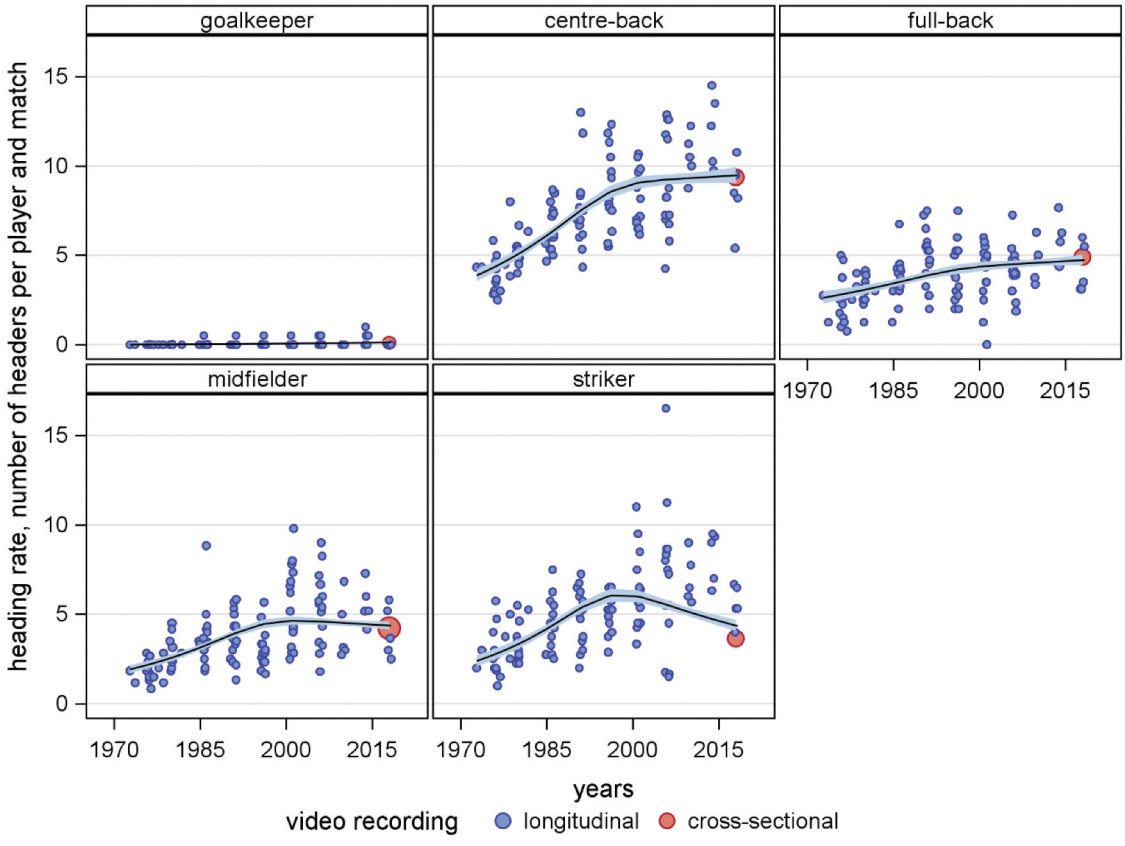

Figure 1. Header rate per play position across 1st Bundesliga seasons based on interpolation by natural cubic splines with 3 knots using Poisson regression.

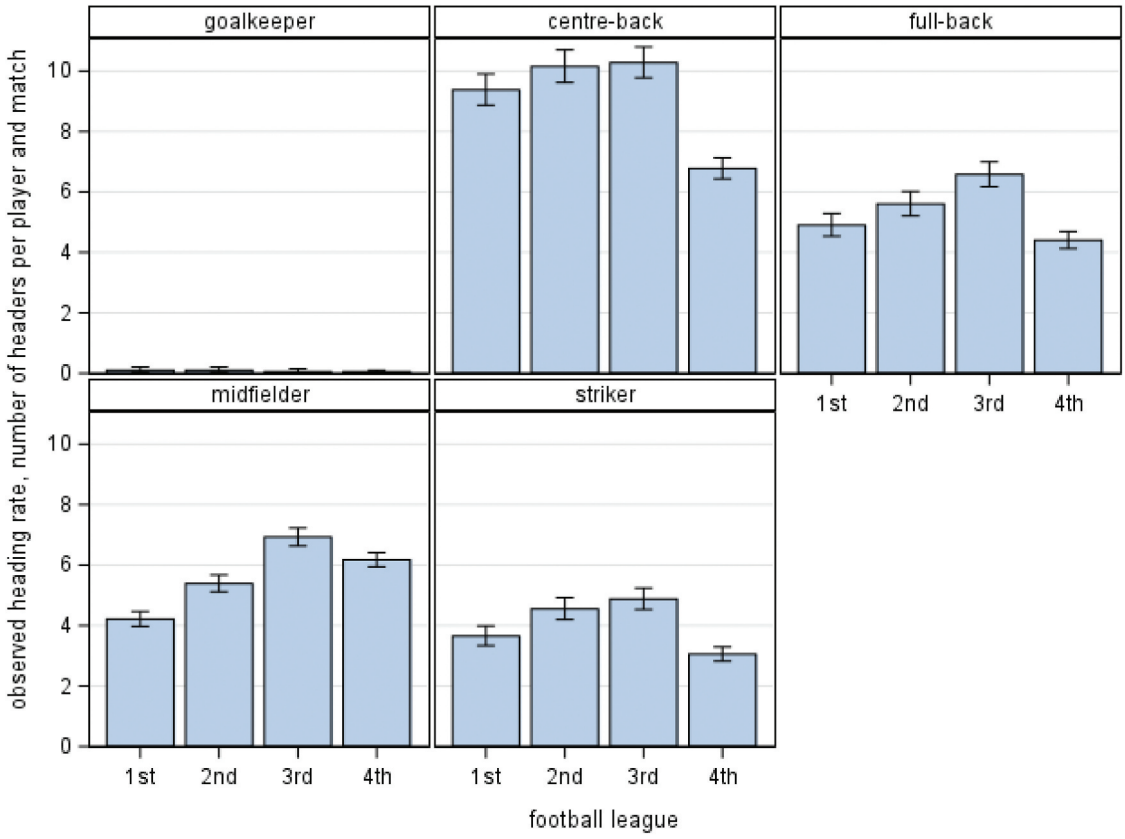

Figure 2. Header frequencies by playing position across four leagues in season 2017/18. 1st = 1. Bundesliga, 2nd = 2. Bundesliga, 3rd = 3. Bundesliga, 4th = 1–2 semi-professional leagues below 3. Bundesliga (Bavarian Regional Football League).

Finally, we evaluated the plausibility of the match-heading index using negative control outcomes, as an exploratory falsification exercise to support its validity. As expected, age at baseline was positively associated with BMI in a linear regression model with slope β = 0.05 (95% confidence interval: 0.01–0.10) and negatively with handgrip strength (β = 0.34, 95% CI: −0.45 – −0.23), both measured at the NAKO baseline examination (Table 1). In contrast, no associations were observed between cumulative match-heading exposure and BMI (β = −0.03, 95% CI: −0.05 – 0.03) or handgrip strength (β = −0.05, 95% CI: −0.04 – 0.15) (Table 1). Results were unchanged in models additionally adjusted for playing position, with associations of age with both BMI and handgrip strength remaining of similar magnitude and no associations observed between cumulative match-heading exposure and either outcome (data not shown). A genuinely non-zero effect of headers on BMI or handgrip strength could only be plausibly explained by confounding or age-related effect modification. The absence of associations suggests that the index is unlikely to be spuriously related to these two general health measures, which is broadly consistent with its plausibility.

Discussion

We present a new approach to estimating match-heading frequency for former professional football (soccer) players by integrating, publicly available career data, and video-analysis-derived heading frequencies stratified by playing position. Modeling match-heading exposure in this way substantially reduces the likelihood of measurement error that typically arises from recall-based assessments, which are susceptible to recall bias – e.g., individuals with head-related symptoms may overestimate their past heading exposure. However, our approach introduces a Berkson-type error (Berkson 1950) by assigning the same heading rate to all players within a given position, league, and season, despite observed individual-level variation (Table 2). Consequently, the index reflects the expected heading exposure for a player defined by playing position, league and season, rather than individualized heading exposure. It does not capture within-position heterogeneity arising from factors such as physical attributes (e.g., height), tactical roles, or skill differences, nor does it account for other sources of head impact exposure

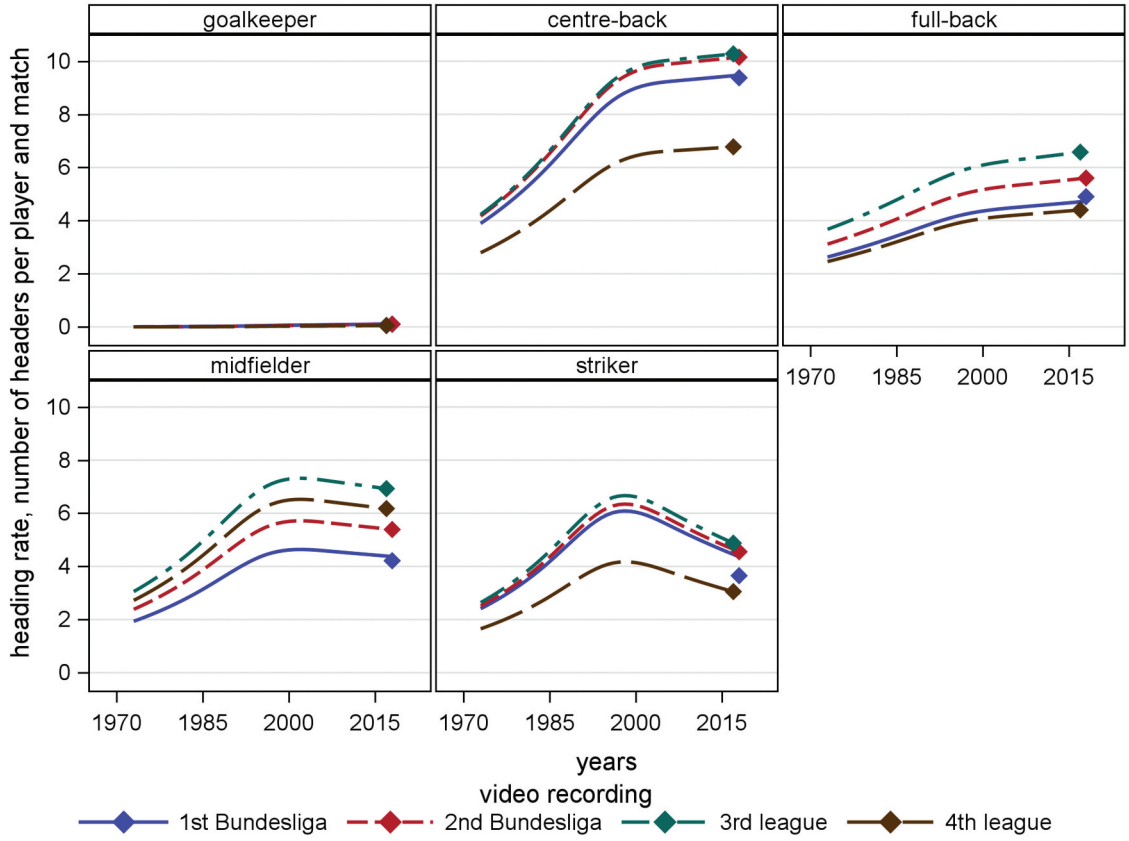

Figure 3. Heading rate across seasons and different leagues, by playing position. Interpolation by natural cubic splines −3 knots using Poisson regression. 1st = 1. Bundesliga, 2nd = 2. Bundesliga, 3rd = 3. Bundesliga, 4th = 1–2 semi-professional leagues below 3. Bundesliga (Bavarian Regional football league).

Table 1. Associations of the match-heading index with (a) body-mass-index (BMI) and (b) handgrip strength as negative control outcomes. Associations were modelled by linear regression with intercept and age. Estimates are factors per unit of the corresponding exposure variable, i.e., per 100 headers and per 1 year of age.

Outcome	Exposure	Estimate	95% CI	p-value
BMI	Number of headers in hundreds	−0.01	−0.05: 0.03	0.597
	age	0.05	0.01; 0.09	0.019
Handgrip strength	Number of headers in hundreds	0.06	−0.04; 0.16	0.226
	age	−0.34	−0.45; −0.23	<0.001

such as collisions, player-to-player contact, falls impact with the ground, or goalpost impacts.

In a recent systematic review, nine studies were identified that investigated heading exposure in 473 former and 452 current football players (Patel et al. 2025). Of these, six studies involving 595 players in total reported evidence of an association between heading exposure and impaired cognitive function. However, eight of these nine studies estimated lifetime heading exposure using self-reported data – typically interviews or questionnaires – which are highly susceptible to recall bias (Matser et al. 1998, 2001; Straume-Naesheim et al. 2005; Koerte et al. 2016; Rodrigues et al. 2019; Prien et al. 2020; Bruno and Rutherford 2022; Espahbodi et al. 2023). In these studies, cumulative heading exposure was calculated by multiplying self-reported heading frequency by the number of matches played over a player's career.

In contrast, our approach applied systematic video analyses based on randomly selected matches per season spanning the decades during which the SoccHealth participants were active. Compared with prior studies, this approach offers several advantages. It explicitly accounts for long-term changes in game strategies and playing styles. We showed that heading frequency per match and playing position has changed considerably over time and differs across the highest

Table 2. Description of the former male professional football players from the SoccHealth cohort.

	N	All (N = 293)	Goalkeeper (N = 22)	Centre-back (N = 80)	Full-back (N = 32)	Midfielder (N = 111)	Striker (N = 48)
Age at SoccHealth examination, mean (sd) years	295	54.5 (8.0)	54.8 (8.2)	55.5 (7.4)	53.2 (10.6)	53.7 (7.8)	54.3 (7.0)
Body mass index (BMI), mean (sd) kg/m^2	290	26,9 (2.9)	26.7 (2.5)	26.7 (2.8)	26.4 (2.6)	26.9 (2.6)	27.6 (4.0)
Height, mean (sd) cm	290	180.2 (5.6)	186.2 (5.5)	183.0 (4.7)	179.1 (4.6)	178.3 (5.1)	178.7 (4.8)
Handgrip strength, mean (sd) kg	293	50.7 (7.9)	51.0 (8.8)	51.6 (8.7)	50.9 (7.6)	50.2 (7.1)	50.2 (8.1)
Self rated header frequency compared with same-position teammates aged 18–39	293						
much more, %	26	8.9	0.0	15.0	0.0	5.4	17.0
. . . .more, %	61	20.8	4.5	30.0	9.4	17.9	27.7
comparable, %	118	40.3	18.2	38.8	71.9	40.2	31.9
less, %	59	20.1	13.6	13.8	18.8	28.6	14.9
much less, %	29	9.9	63.6	2.5	0	8.0	8.5
Number of seasons played		3,757	282	1,005	444	1,462	564
Sum of playing hours*	295						
1st Bundesliga		48,158.2	3,881.3	14,068.6	5,632.9	18,001.4	6,574.0
2nd Bundesliga		30,895.6	1,643.5	8,218.3	3,760.6	12,260.7	5,012.5
3rd Bundeliga		1,749.9	173.9	284.9	273.3	911.3	106.5
1–2 semi-professional leagues (Bavarian Regional Leagues)		35,364.6	2,669.8	9,298.3	4,273.2	14,095.0	5,028.3
Total		116,168.3	8,368.5	31,870.1	13,940.0	45,268.4	16,721.2
Reported head injuries[#]							
number		190	6	62	27	73	22
rate per 100 playing hours		0.164	0.072	0.195	0.194	0.161	0.131
Estimated heading exposure							
number		389,076	189	150,364	38,767	147,016	52,740
rate		334.9	2.3	471.8	278.1	324.8	315.4

Playing positions are based on the player's primary self-report position. *Total playing hours are derived by the kicker and Transfermarkt databases. [#]Head injuries are defined as those resulting in a playing absence of at least 28 days.

German leagues. By analyzing video material, we substantially reduced recall bias, a major limitation of previous investigations. Furthermore, we quantified marked differences in heading frequency across playing positions. Heading rates were averaged across 15 matches per season and modeled at five-year intervals, providing a sufficiently fine temporal resolution for longitudinal exposure assessment. A comparable statistical approach, albeit based on self-reported heading frequencies, was used in a recent study (Gallo et al. 2024) that modelled cumulative heading exposure across a player's entire career, including youth and post-retirement periods.

There are a number of limitations to the present approach. First, multi-decade video material was available only for the 1st Bundesliga, necessitating extrapolation to lower leagues. Second, video data covering all league levels were available for only a single season. We therefore adopted a pragmatic temporal grid of 15 matches per season at five-year intervals and extrapolated to other leagues by applying empirically derived inter-league proportionality factors from the cross-league dataset. While a finer grid might have yielded more precise estimates, we consider it unlikely that this would have materially altered the results. Nonetheless, this extrapolation depends critically on the assumption that historical heading habits in lower leagues, relative to the 1st Bundesliga, were proportional to those observed in the 2017/18 season. Third, while video material enables the estimation of average heading counts by position, season, and league, they cannot quantify the absolute number of headings performed by individual players. A recent calibration study showed that male football players tend to underreport their true heading exposure; however, the study also concluded that well-derived indices offer consistent and reliable estimates, meaning that individual self-reports would not necessarily provide more accurate data (Catenaccio et al. 2016). Fourth, information on heading during childhood and youth is not included. Although a recent pan-European study assessed heading incidence in children's and youth football, the available data come only from the 2017/18 and 2018/19 seasons (Beaudouin et al. 2020). Extrapolating these findings to earlier decades is not straightforward, which prevented their incorporation into the current models. Fifth, in the absence of a gold standard for lifetime match-heading exposure, direct validation of the index was not possible. Instead, we conducted an exploratory falsification analysis of the match-heading index using two negative control outcomes. An observed association with a negative control, which is not causally related to the heading index, would raise concerns about the index' validity. Sixth, information on headers during training was unavailable and training practice has changed over time. However, headers in training sessions may account for a substantial – and possibly dominant – share of total header exposure compared to matches. Seventh, the match-heading index cannot be directly applied to (former) professional female football players.

Nevertheless, the underlying remains transferable, provided that comparable longitudinal and cross-league data for women's football are available. Eighth, the available data do not permit differentiation between different qualities or types of headings, such as long versus short aerial trajectories or duelled vs. non-duelled headers. Consequently, the index captures the estimated number of match headers over time, an important but incomplete measure of biologically relevant exposure.

In summary, we present a novel match-heading index for former male professional football (soccer) players that enables quantitative estimation of time-varying match headers frequency across an individual's career. By accounting for differences in heading frequency by playing position, career duration, and temporal changes in playing style, this index provides a robust exposure metric for future epidemiologic studies investigating the long-term neurological consequences of match-heading frequency in professional football.

Acknowledgements

We thank all SoccHealth participants and all study staff for their commitment and engagement in the study. We are also grateful to Florian Wehowsky for extracting the former professional players' career data – specifically playing position and playing time – from the kicker and transfermarkt databases. This project was conducted with data (No. NAKO-904) from the SoccHealth satellite project to the German National Cohort (NAKO, www.nako.de). SoccHealth is funded by Deutscher Fußball-Bund DFB (German Football Association), Deutsche Fußball Liga DFL (German Soccer League), Verwaltungsberufsgenossenschaft vbg (Employer's Liability Insurance Association), and the German Ministry of Education and Research (BMBF, grant # 01KX2020A). NAKO is funded by the Federal Ministry of Education and Research (BMBF grant #: 01ER1301A/B/C,01ER1511D, 01ER1801A/B/C/D and 01ER2301A/B/C], the German federal states, the Helmholtz Association, as well as by the participating universities and institutes of the Leibniz Association.

KB and TM implemented the SoccHealth project. HB, JW and KB developed the algorithm for the exposure index, WK, CR, TM provided video material and/or analyses, MA performed video analyses. HB, JW, TM, KB, MS, and ML contributed to drafting the manuscript. All coauthors provided comments and editing to the final manuscript version.

Author contributions

CRediT: **Hansjörg Baurecht:** Data curation, Methodology, Writing – original draft, Writing – review & editing; **Jürgen Wellmann:** Data curation, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing; **Michael J. Stein:** Writing – review & editing; **Michael F. Leitzmann:** Writing – review & editing; **Mike Abroscheit:** Data curation, Investigation, Writing – review & editing; **Claus Reinsberger:** Writing – review & editing; **Tim Meyer:** Conceptualization, Funding acquisition, Project administration, Writing – review & editing; **Klaus Berger:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

TM is chairman of the DFB´s and the European Football Confederation´s (UEFA´s) medical committee and DFL´s working group 'Medicine in Professional Football'. He is also member of FIFA's medical committee.

CR is a member of the DFB's medical committee and is an advisor on head injuries for UEFA. He receives funding for a scientific project from UEFA and has acted as speaker at medical conferences for DFB and UEFA.

WK is member of the medical committee of the DFB, member in the DFL working group 'Medicine in Professional Football' and chief medical officer of the Bavarian Football Association (BFV)

Funding

The work was supported by the Bundesministerium für Forschung, Technologie und Raumfahrt [01KX2020A].

ORCID

Hansjörg Baurecht http://orcid.org/0000-0002-9265-5594
Jürgen Wellmann http://orcid.org/0000-0003-3635-8584
Michael J. Stein http://orcid.org/0000-0002-1120-1751
Michael F. Leitzmann http://orcid.org/0000-0002-0371-2789
Claus Reinsberger http://orcid.org/0000-0002-0283-5963
Werner Krutsch http://orcid.org/0000-0002-2916-9606
Tim Meyer http://orcid.org/0000-0003-3425-4546
Klaus Berger http://orcid.org/0000-0001-8966-3684

Data and code availability statement

The datasets generated and analysed during the current study are not publicly available. For NAKO data access, an official data access proposal has to be submitted. The video analyses data may be available from the authors on reasonable request.

The analytic code used in this study is available from the corresponding author upon request.

References

Beaudouin F et al. 2020. The UEFA heading study: heading incidence in children's and youth' football (soccer) in eight European countries. Scand Med Sci Sports. 30(8):1506–1517. https://doi.org/10.1111/sms.13694

Berger K et al. 2024. SoccHealth: a health status examination of former professional football (soccer) players within the German National cohort. BMJ Open Sport Exerc Med. 10(4): e002228. https://doi.org/10.1136/bmjsem-2024-002228

Berkson J. 1950. Some observations with respect to the error of bio-assay. Biometrics. 6(4):432. https://doi.org/10.2307/3001787

Bruno D, Rutherford A. 2022. Cognitive ability in former professional football (soccer) players is associated with estimated heading frequency. J Neuropsychol. 16(2):434–443. https://doi.org/10.1111/jnp.12264

Catenaccio E et al. 2016. Validation and calibration of HeadCount, a self-report measure for quantifying heading exposure in soccer players. Res Sports Med. 24(4):416–425. https://doi.org/10.1080/15438627.2016.1234472

Chilmeran Z, Akhtar MU, Sharafeldin A-BK, Gaynor D. 2025. Concussion injuries in sports and the role of instrumented mouthguards: a mini review. Front Bioeng Biotechnol. 13:1567429. https://doi.org/10.3389/fbioe.2025.1567429

DFL Sportcast Media Portal. 2023.

Espahbodi S et al. 2023. Heading frequency and risk of Cognitive impairment in retired male professional soccer players. JAMA Netw Open. 6(7):e2323822. https://doi.org/10.1001/jamanetworkopen.2023.23822

Gallo V et al. 2024. Cognitive function among former professional male soccer players – the HEADING study. Preprint at https://doi.org/10.1101/2024.03.26.24304885

Koerte IK et al. 2016. Cortical thinning in former professional soccer players. Brain Imag Behav. 10(3):792–798. https://doi.org/10.1007/s11682-015-9442-0

Mackay DF et al. 2019. Neurodegenerative disease mortality among former professional soccer players. N Engl J Med. 381(19):1801–1808. https://doi.org/10.1056/NEJMoa1908483

Matser JT, Kessels AGH, Jordan BD, Lezak MD, Troost J. 1998. Chronic traumatic brain injury in professional soccer players. Neurology. 51(3):791–796. https://doi.org/10.1212/WNL.51.3.791

Matser JT, Kessels AGH, Lezak MD, Troost J. 2001. A dose-response relation of headers and concussions with Cognitive impairment in professional soccer players. J Clin Exp Neuropsychol. 23(6):770–774. https://doi.org/10.1076/jcen.23.6.770.1029

Orhant E et al. 2022. A retrospective analysis of all-cause and cause-specific mortality rates in French male professional footballers. Scand Med Sci Sports. 32(9):1389–1399. https://doi.org/10.1111/sms.14195

Patel L, Tarafder J, Ronca F. 2025. Cognitive effects of heading in professional football: a systematic review. Int J Sports Med. 46(3):151–163. https://doi.org/10.1055/a-2409-0323

Peters A et al. 2022. Framework and baseline examination of the German National cohort (NAKO). Eur J Epidemiol. 37(10):1107–1124. https://doi.org/10.1007/s10654-022-00890-5

Prien A, Feddermann-Demont N, Verhagen E, Twisk J, Junge A. 2020. Neurocognitive performance and mental health of retired female football players compared to non-contact sport athletes. BMJ Open Sport Exerc Med. 6(1):e000952. https://doi.org/10.1136/bmjsem-2020-000952

R Core Team. 2024. R: a language and environment for statistical computing. R Foundation for Statistical Computing.

Rodrigues AC et al. 2019. No evidence of Association between soccer heading and Cognitive performance in professional soccer players: cross-sectional results. Front Neurol. 10:209. https://doi.org/10.3389/fneur.2019.00209

Roe G et al. 2024. Embracing the *impact* from instrumented mouthguards (iMgs): a survey of iMG managers' perceptions of staff and player interest into the technology, data and barriers to use. Eur J Sport Sci. 24(6):670–681. https://doi.org/10.1002/ejsc.12101

Sandmo SB et al. 2022. Changes in circulating microRNAs following head impacts in soccer. Brain Inj. 36(4):560–571. https://doi.org/10.1080/02699052.2022.2034042

SAS Software. 2023. SAS institute Inc.

Schipf S et al. 2020. The baseline assessment of the German National cohort (NAKO Gesundheitsstudie): participation in the examination modules, quality assurance, and the use of secondary data. Bundesgesundheitsbl Gesundheitsforsch Gesundheitsschutz. 63(3):254–266. https://doi.org/10.1007/s00103-020-03093-z

Straume-Naesheim TM, Andersen TE, Dvorak J, Bahr R. 2005. Effects of heading exposure and previous concussions on neuropsychological performance among Norwegian elite footballers. Br J Sports Med. 39(suppl 1):i70–i77. https://doi.org/10.1136/bjsm.2005.019646

Transfermarkt. 2024.

Ueda P et al. 2023. Neurodegenerative disease among male elite football (soccer) players in Sweden: a cohort study. Lancet Public Health. 8(4):e256–e265. https://doi.org/10.1016/S2468-2667(23)00027-0

Weber J et al. 2023. Heading and risk of injury situations for the head in professional German football: a video analysis of over 150,000 headers in 110,000 match minutes. Sci Med Football. 7(4):307–314. https://doi.org/10.1080/24733938.2022.2114602