

Heading Exposure in Elite Football (Soccer): A Study in Adolescent, Young Adult, and Adult Male and Female Players

SHARI LANGDON^{1,2,3}, EDWIN GOEDHART², JAAP OOSTERLAAN^{1,3}, and MARSH KÖNIGS^{1,3}

¹Emma Neuroscience Group, Department of Pediatrics, Emma Children's Hospital, Amsterdam UMC, University of Amsterdam, Amsterdam, THE NETHERLANDS; ²Football Medical Centre, Royal Netherlands Football Association (KNVB), Zeist, THE NETHERLANDS; and ³Amsterdam Reproduction and Development Research Institute, Amsterdam, THE NETHERLANDS

ABSTRACT

LANGDON, S., E. GOEDHART, J. OOSTERLAAN, and M. KÖNIGS. Heading Exposure in Elite Football (Soccer): A Study in Adolescent, Young Adult, and Adult Male and Female Players. *Med. Sci. Sports Exerc.*, Vol. 54, No. 9, pp. 1459–1465, 2022. **Purpose:** This study aims to quantify heading exposure in real-life elite football at the level of individual male and female adolescents, young adults, and adults. **Methods:** Heading exposure was determined by video analysis in combination with a structured electronic registration tool and observation training, to comprehensively register heading characteristics. Characteristics of heading events were registered in 116 official matches (96 male, 20 female) of Dutch national teams. **Results:** Mean exposure for male players based on full match participation was 4.2 headers, with maximum heading exposure at 10.6 headers. Mean heading exposure was higher in adult than adolescent players ($P = 0.049$), whereas maximum heading exposure was higher for adult than for young adult players ($P = 0.045$). Maximum heading exposure was higher in male than in female players ($P = 0.015$). Defenders had the greatest mean and maximum heading exposure ($P < 0.001$). Longer flight courses of the ball had greater contribution to mean and maximum heading exposure than shorter courses ($P < 0.01$). Frontal headers had greater contribution to exposure than other points of contact on player's head ($P < 0.001$), whereas linear headers had greater contribution than rotational headers ($P = 0.016$). Defensive headers had greater contribution to exposure than other heading types ($P < 0.014$). Unintentional head contacts in elite football players were, in most cases (80%), not related to heading situations. **Conclusions:** This study provides real-life quantifications of mean and maximum heading exposure in elite football, with strong relevance for policy makers and researchers. The results highlight the roles of player and heading characteristics in heading exposure, informing current discussions on the role of heading in football. **Key Words:** FOOTBALL, HEADING, MATCH ANALYSIS, VIDEO RECORDING

Football is the most popular sport in the world, with over 265 million active players worldwide (1). Football is also unique in that players are allowed to use the head to play the ball (2). Concerns have been raised about these purposeful

headings and their potential negative effect on the brain (2–6). A large record linkage study suggests that former professional Scottish football players (active in 1900s) had an increased risk of mortality due to neurodegenerative disease (7) especially for defenders (8), although the role of heading in such effects remains unknown. Since 2015, heading the ball in youth football has been limited or banned for players up to 12 yrs in the United States (9). The English Football Association has recently presented new protocols for adults that place limits on heading frequency during training sessions (10). These developments highlight the relevance of research investigating heading in football.

Contrasting with policy changes in recent years, recent (systematic) reviews and meta-analyses on the short- and long-term effects of football heading have found no evidence for an effect of heading exposure on brain structure, brain function, or perceived symptoms (11–14). The available literature is limited regarding long-term cumulative consequences of repetitive heading, primarily because of methodological shortcomings of the available studies, such as the use of retrospective study design that relies on unreliable subjective reports of heading exposure (15,16). Prospective studies are scarce, although two studies reported evidence for acute transient effects of heading

Address for correspondence: Shari Langdon, M.Sc., Emma Children's Hospital, Meibergdreef 9, Amsterdam 1105AZ, the Netherlands; E-mail: s.langdon@amsterdamumc.nl.

Submitted for publication December 2021.

Accepted for publication April 2022.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.acsm-msse.org).

0195-9131/22/5409-1459/0

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DOI: 10.1249/MSS.0000000000002945

exposure on postural control, electrophysiological and cognitive functioning (17,18). These small-sized studies ($N < 19$) investigated the impact of exposure to 20 rotational headers at an average speed of $38 \text{ km}\cdot\text{h}^{-1}$ within a 10-min time period. Although the results suggest a potentially short-lived negative impact of heading at certain levels of exposure, the representativeness of these findings for real-life exposure to heading remains unclear.

To allow prospective studies to investigate the impact of heading at realistic exposure, there is a need for quantification of real-life heading exposure. Previous studies have attempted to quantify heading exposure through various approaches. Skin patch sensors have been used in high school and collegiate male and female football players (19–23), to measure head acceleration. This method does not allow visual confirmation of the acceleration event, limiting the ability to discriminate between different causes of head acceleration. Real-time observations do allow visual confirmation of events as headers (24,25), but are also limited in the ability to gather contextual information (e.g., player position, type of play, etc.) because of the fast pace at which subsequent headers can occur. Video observations may be the preferred method for quantification of heading exposure with visual confirmation of the header event and appreciation of contextual information.

Studies using video observations in children's and youth football indicate that match exposure to heading increases with age (26) and is higher in male than in female players (27). Video observations in children and adolescents also indicate relevance of contextual information, showing that heading is more prevalent during free gameplay (rather than after game continuations because of goalkeeper kicks, free kicks, or corner kicks) and after shorter flight courses of the ball (less than 5 m) (27). These findings may suggest that not only the frequency but also the impact of heading exposure may be lower for younger players than for adult players. Likewise, heading exposure has also been observed to differ between player positions (28,29) and to be higher in professional rather than amateur players (24). Although there is limited view on maximum heading exposure (compared with mean heading exposure), some studies using video recording (26,29) or real-time observation (19,20,24) indicate strong interindividual variation in (maximum) heading exposure, warranting recording of header events at the level of individual players. This could be regarded as vital information for studies that experimentally investigate the impact of heading at realistic maximum exposure.

This study aims to quantify heading exposure in real-life in adolescent, young adult, and adult male and female elite football players using a structured electronic registration tool for comprehensive video observation. The results of this study can be used as objective information source for current discussions on policy changes regarding heading in football. Likewise, the results may feed high-quality prospective studies investigating with realistic estimations of heading exposure in elite football.

MATERIALS AND METHODS

Study Design

An observational study design was used to quantify heading exposure in real-life elite football in adolescents, young adults,

and adults in 116 official male and female matches during a 5-yr period (2016–2020) captured by video recording.

Participants

Sample. This study used video recordings of 96 official matches from male national teams of the Netherlands. To obtain a representative sample of matches over time, we sampled video recordings of official matches over a 5-yr period (2016–2020). We stratified for age, by selecting eight matches per age group. This resulted in 32 matches for male adolescents (i.e., U-15, U-16, U-17, and U-18), 24 for male young adults (i.e., U-19, U-20, U-21). Lastly, 40 matches were selected for male adults (i.e., 8 matches per year). To investigate sex differences, we also selected official matches of female national teams. Because of limited availability of video recordings, we selected 20 matches also stratified across age groups. For this study, all video recording had been aired in the public domain, not necessitating informed consent to be obtained.

Measures

Heading characteristics. We developed a structured heading registration tool to allow comprehensive registration of headers from video recordings, integrated in MyVideoAnalyser version 2.6.13 (MyVideoAnalyser, s-Hertogenbosch, the Netherlands) (30). The registration tool was developed in close collaboration with video analysts of the Royal Netherlands Football Association. To increase the reliability of registration, definitions of all heading characteristics were articulated on the basis of consensus meetings with experienced trainers, players and video analysts, and were subsequently fine-tuned based on experience gained in a pilot phase. Video examiners watched the recordings of matches for heading events, registering heading player, player position, match situation (i.e., type of match situation and flight course of the ball), header direction (i.e., linear and rotational), point of contact on player's head, heading type (e.g., defensive, passing), unintentional head contact, potential head injury, and pitch location (see Supplemental Table 1, Supplemental Digital Content 1, which shows the definitions of heading characteristics, <http://links.lww.com/MSS/C593>).

Procedure

Training, quality control, and registration. To optimize the reliability of registration, we developed a training procedure for examiners. After a briefing about the study goals and procedures, examiners received a hands-on training by one of the authors (S. L.) using a standardized protocol. After the training, examiners could enroll for test registrations that provided insight into the registration quality of the examiner. Test registrations were performed on matches with an available reference registration, which was based on consensus between independent registrations by two members of the core research team (M. K. and S. L.) that were highly involved in the development of the registration tool. Differences between the examiner's registration and the reference registration were assessed by intraclass coefficients (ICC). Examiners received personal feedback based

on the test registration results. Examiners with excellent test registration scores ($ICC \geq 0.90$) on preselected core registration characteristics (see Supplemental Table 1, Supplemental Digital Content 1, for preselected core registration characteristics, <http://links.lww.com/MSS/C593>) successfully completed the training phase and entered the independent registration phase. Examiners with test registration $ICC < 0.90$ were asked to check each header event for agreements and deviations and continued training by registering another match. This cycle was repeated until an ICC of ≥ 0.90 was reached. The average registration quality across examiners regarding the total number of header events per match at successful completion of the training phase was excellent (mean ICC , 0.996; range, 0.994–0.999), indicating strong coherence between examiner registrations and the reference registration (see Supplemental Table 1, Supplemental Digital Content 1, for $ICCs$ of the other preselected core registration characteristics after training, <http://links.lww.com/MSS/C593>). During the independent registration phase, all examiners again blindly performed at least one test registration to monitor the quality of registration during the independent registration phase. The average registration quality across examiners regarding the total number of header events per match remained to be excellent during the registration phase (mean ICC , 0.998; range, 0.994 to 0.999). In the registration phase, the selected matches were assigned to examiners in pseudo-randomized fashion, so that each examiner registered a balanced cross section of the match sample as much as possible (e.g., in terms of year, age, sex).

Statistical Analysis

All analyses were performed in R Studio version 3.6.1 (31). All dependent variables were screened for outliers using box plots, which were subsequently rescaled using Winsorizing with the “DescTools” package (32). In addition, dependent measures that were not normally distributed were subjected to van der Waerden transformation, using the “BestNormalize” package in R (33).

In all analyses, match was used as the unit of analysis. We used two dependent variables: the *mean match exposure* and the *maximum match exposure*. The mean match exposure was defined by the mean number of headers in a match per player. The maximum match exposure was defined by the maximum number of headers by one and the same player in one match. For details on the calculation of exposure variables, see Supplemental Table 2 (Supplemental Digital Content 2, Overview of sample and dependent variable(s) used in the analysis, <http://links.lww.com/MSS/C594>).

Dependent variables were subjected to ANOVA to test the effects of between-subject variables (i.e., player characteristics: age, sex, and player position) and within-subject variables (i.e., heading characteristics: match situation, header direction, point of contact on player’s head, and heading type). For categorical variables with more than two levels, significant main effects were followed up by *post hoc* testing comparing all categories using Tukey tests. For categorical variables with more than three categories, *post hoc* analysis was corrected for multiple comparisons by controlling the false discovery rate (34).

All statistical testing was two-sided at $\alpha = 0.05$, and effect sizes were expressed as η^2 (for main effects) or Cohen’s d (for group differences).

RESULTS

We analyzed 96 official matches of elite male football players, in which a total of 8160 heading events were registered. Additional characteristics of the registrations are presented in Table 1. In the 96 matches, the mean match exposure was 4.2 headers per player based on full-match play (SD, 1.1; range, 2.6–6.6), and the maximum match exposure was 10.6 headers per player (SD, 3.2; range, 5–20). A total of 50 unintentional head contacts were observed, with 20% occurring during a heading event. These unintentional head contacts included any type of contact to the head (e.g., a hand from a player touching the head of another player) but could be considered to reflect situations that increase the risk of sustaining concussion. In 98% of the unintentional head contacts, the player continued in match play. Figure 1 displays an overview of player and heading characteristics per match of the 96 analyzed matches.

Player Characteristics

Age. As shown in Table 1, a main effect of age was found for mean match exposure to heading, indicating that mean match exposure was higher for older players ($F_{2,93} = 3.7$, $P = 0.028$, $\eta^2 = 0.07$). *Post hoc* group comparisons showed that mean match exposure was higher in adult players than in adolescent players ($P = 0.049$, $d = 0.52$), whereas other group differences were not significant ($P > 0.079$, $d < 0.63$). Likewise, maximum match exposure was different for age groups ($F_{2,93} = 3.9$, $P = 0.023$, $\eta^2 = 0.08$), with *post hoc* tests revealing that the maximum number of headers per player in a match is higher for adult players than for young adult players ($P = 0.045$, $d = 0.62$), whereas other group differences were not significant ($P > 0.063$, $d < 0.55$).

Sex. Table 2 displays the comparison between male players and female players in a matched subsample on mean and maximum match exposure to heading. There was no significant effect of sex on mean match exposure ($F_{1,38} = 1.7$, $P = 0.196$, $d = 0.41$; male: mean \pm SD, 4.0 ± 1.0 ; female: mean \pm SD, 3.6 ± 1.1). However, the maximum match exposure was different for sexes ($F_{1,38} = 6.4$, $P = 0.015$, $d = 0.78$), with the maximum number of headers per match for male players (mean \pm SD, 10.4 ± 2.1) being higher than for female players (mean \pm SD, 8.6 ± 2.3).

Player position. Because goalkeepers accounted for 0.1% of headers per match (Fig. 1), goalkeepers were omitted from the analysis. We found a significant main effect of player position on mean match exposure ($F_{2,190} = 160.4$, $P < 0.001$, $\eta^2 = 0.41$), where significant differences were observed between all positions (see Supplemental Table 3, Supplemental Digital Content 3, which shows the effect of player position on mean and maximum match exposure to heading, <http://links.lww.com/MSS/C595>). Defenders had higher mean match exposure than all other positions ($P < 0.001$, $d > 1.58$) and

TABLE 1. Total number of matches, headers, heading players, unintentional head contacts, and mean and maximum match exposure per age group.

Groups	Adolescents	Young Adults	Adults	Total		
Totals	U-15 U-16 U-17 U-18	U-19 U-20 U-21	National team			
No. matches, <i>n</i>	32	24	40	96		
Total headers, <i>n</i>	2549	1895	3716	8160		
Total heading players, <i>n</i>	725	524	891	2140		
Unintentional head contacts, <i>n</i>	10	13	27	50		
During heading, <i>n</i> (%)	3 (30.0)	1 (7.7)	6 (22.2)	10 (20.0)		
Loss of consciousness, <i>n</i> (%)	0 (0)	0 (0.0)	0 (0.0)	0 (0.0)		
Directly substituted, <i>n</i> (%)	0 (0)	0 (0.0)	1 (3.7)	1 (2.0)		
Continued in match play, <i>n</i> (%)	10 (100.0)	13 (100.0)	26 (96.3)	49 (98.0)		
Per Match					P	Contrasts
Mean match exposure, M (SD)	4.0 (1.1)	3.9 (1.0)	4.6 (1.2)	4.2 (1.1)	0.049	Adults > adolescents
range	2.7–6.0	2.7–6.7	2.7–6.7	2.6–6.6		
Maximum match exposure, M (SD)	10.0 (2.9)	9.7 (3.1)	11.7 (3.3)	10.6 (3.2)	0.045	Adults > young adults
range	5–16	6–19	7–20	5–20		

M, mean; SD, standard deviation.

midfielders higher than strikers ($P < 0.01$, $d = 0.27$). The effect of player position on maximum match exposure was also significant ($F_{2,175} = 116.8$, $P < 0.001$, $\eta^2 = 0.33$), where defenders had higher maximum match exposure than all other positions ($P < 0.001$, $d > 1.40$), whereas other group differences were not significant ($P > 0.068$, $d < 0.21$).

Heading Characteristics

Supplemental Table 3 (Supplemental Digital Content 3, <http://links.lww.com/MSS/C595>) also displays comparisons of heading characteristics: match situation, header direction, point of contact on player's head, and heading type on expected and maximum match exposure.

Match situation. A significant effect of match situation on mean match exposure was found ($F_{6,579} = 208.0$, $P < 0.001$, $\eta^2 = 0.623$), where mean match exposure was

significantly larger for player passes covering >20 m compared with all other match situations ($P < 0.001$, $d > 0.67$). There was also a significant effect of match situation on maximum match exposure ($F_{7,655} = 143.0$, $P < 0.001$, $\eta^2 = 0.548$), where maximum match exposure was significantly larger for player passes covering >20 m than for all other match situations ($P < 0.001$, $d > 0.68$; see Supplemental Table 3 (Supplemental Digital Content 3, Mean and maximum match exposure according to player and heading characteristics), <http://links.lww.com/MSS/C595> for a complete overview of *post hoc* group comparisons).

Header direction. Although there was no significant effect of header direction on mean match exposure ($F_{1,95} = 3.6$, $P = 0.061$, $d = 0.27$), there was an effect on maximum match exposure ($F_{1,95} = 6.0$, $P = 0.016$), where the maximum match exposure for linear headers was greater than for rotational headers ($d = 0.34$).

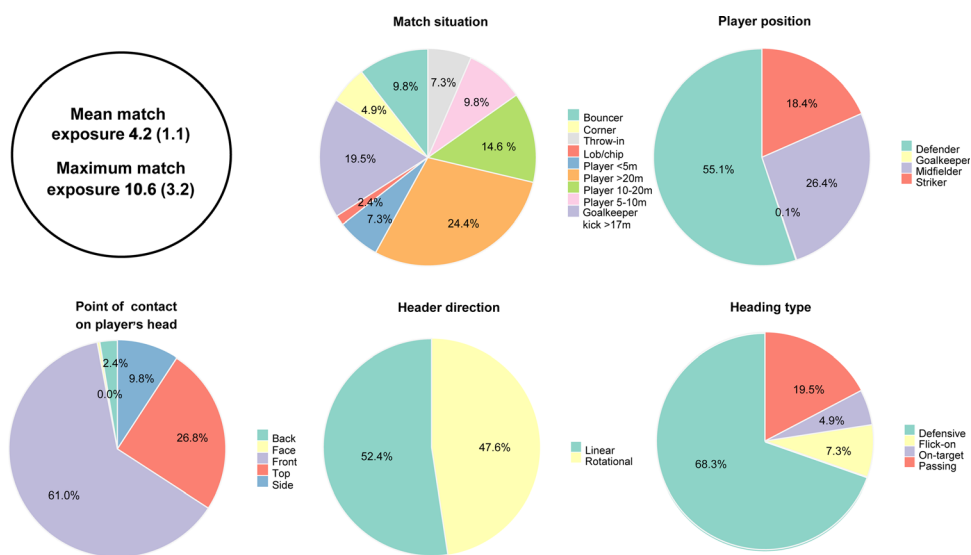


FIGURE 1—Overview of heading registration results.

TABLE 2. Mean and maximum match exposure between sexes.

	Male (n = 20)		Female (n = 20)		Contrasts
	M (SD)	Range	M (SD)	Range	P
Mean match exposure	4.0 (1.0)	2.3–5.7	3.6 (1.1)	2.1–5.7	0.196
Maximum match exposure	10.4 (2.1)	6.0–13.1	8.6 (2.3)	6.0–13.1	0.015

M, mean; SD, standard deviation.

Point of contact on player's head. The effect of the point of contact on player's head on mean match exposure was significant ($F_{3,323} = 602.6, P < 0.001, \eta^2 = 0.82$), revealing differences between all points of contact ($P < 0.001, d > 1.41$). More specifically, mean match exposure on the forehead was greater than for all other points of contact ($P < 0.001, d > 2.15$). There was also a significant main effect of point of contact on maximum match exposure ($F_{4,346} = 501.1, P < 0.001, \eta^2 = 0.78$), where significant differences were observed between all points of contact ($P < 0.001, d > 0.47$). More specifically, the maximum match exposure on the forehead was greater than for all other points of contact on player's head ($P < 0.001, d > 1.85$; see Supplemental Table 3 (Supplemental Digital Content 3, Mean and maximum match exposure according to player and heading characteristics, <http://links.lww.com/MSS/C595>) for a complete overview of *post hoc* group comparisons).

Heading type. We found a significant main effect of heading type on mean match exposure ($F_{2,241} = 329.9, P < 0.001, \eta^2 = 0.69$), where significant differences between all heading types were observed ($P < 0.010, d > 0.45$). More specifically, the mean match exposure for defensive heading types was greater than for all other heading types ($P < 0.001, d > 3.62$). There was also a significant main effect of heading type on maximum match exposure ($F_{3,251} = 501.6, P < 0.001, \eta^2 = 0.77$), where there were differences between all heading types ($P < 0.014, d < 0.33$). More specifically, the maximum match exposure for defensive heading types was greater than for all other heading types ($P < 0.001, d > 3.38$; see Supplemental Table 3 (Supplemental Digital Content 3, Mean and maximum match exposure according to player and heading characteristics, <http://links.lww.com/MSS/C595>) for a complete overview of *post hoc* group comparisons).

DISCUSSION

This study aimed to quantify heading exposure in real-life football at the level of individual elite male and female players from adolescence to adulthood. The results provide quantifications of mean and maximum exposure to heading per match. Furthermore, the results indicate that player characteristics (i.e., age, sex and player position) and heading characteristics (i.e., match situation, header direction, point of contact on player's head, and heading type) play a role in heading exposure. These findings have strong relevance for future policy and research regarding the role of heading in football.

This study revealed a mean heading exposure substantiating to 4.2 headers per match based on full-time participation. Considering the 1-SD range around this estimation (3.1–5.3), our result is comparable to that of another study in (semi)professional

football players (5.1 headers per match) (24). Interestingly, studies using skin patch accelerometers to count head impacts retrieve much higher heading exposures (>7.2 headers per match) (19,20), suggesting that this technique, which does not provide the opportunity of visual confirmation, may overestimate heading exposure. Regarding maximum match exposure, we found that the player with the highest match exposure on average headed 10.6 balls per match. This finding extends the literature on maximum heading exposure at the highest level of football participation.

Results of the analyses focusing on player characteristics indicate that mean and maximum match exposure to heading is higher in adults than in younger players. This finding aligns with previous work on amateur youth football players (12–19 yr old), where age-related increases in heading exposure were reported (24,26,27). The current study extends this finding by showing that at elite level, adult players have highest exposure to heading. Our findings indicate no difference between sexes in mean match exposure, whereas maximum match exposure is greater for male players than female players. Regarding player position, the results indicate that mean match exposure is greatest for defenders, followed by midfielders and subsequently by strikers. This finding is in line with recent studies (28,29) but contrasts with other skin patch sensor observations, suggesting head impact exposure to be the greatest for midfielders (19,22). Again, this may suggest that skin patch sensor studies may record events that are not specific to heading (e.g., head movement inherent to dynamic game play). Considering that heading has been reported to be higher in elite players than in amateur players (24), our findings suggest that elite players with adult age, male sex, and defending player position should be considered to have the greatest heading exposure in football.

Regarding the analyses of heading characteristics, results indicate that mean and maximum heading exposure was greatest for defensive heading compared with all other types. This is consistent with our findings indicating that heading exposure is greatest for defenders. This study also indicates that mean and maximum heading exposure is greatest for longer flight courses of the ball (i.e., player passes >20 m and goalkeeper kicks >17 m) rather than shorter flight courses. This contrasts with a study showing that heading by children and adolescent players was most frequent during free gameplay and after shorter flight courses of the ball (<5 m) (27), which may be explained by the older age range of players in the current study (coinciding with greater field dimensions and greater muscle force to shoot the ball over longer distance). With regard to header direction, results indicate that maximum heading exposure was greater for linear headers rather than rotational headers. The relevance of this finding lies in the proposition that rotational headers are associated with higher mechanical impact of heading (35). Likewise, the literature shows that the point of contact on a player's head was found to be associated with the rotational velocity of headers, such that an improper technique of heading the ball (i.e., on top of the head) resulted in a larger peak rotational velocity than proper techniques (i.e., forehead) (36). Our study results show that mean and maximum heading

exposure was greatest for impact locations at the forehead, leaving a considerable proportion of headers (27%) associated with a point of contact that may reflect suboptimal heading technique. Taken together, these findings indicate that heading characteristics should be taken into account when evaluating heading exposure.

The current study has some strengths and limitations. First, this study was performed for matches of Dutch national teams. Therefore, the results are not directly generalizable to nonelite levels of football. Likewise, we have not included young children in our sample. Also, because of our focus on matches featuring Dutch national teams, potential effects of playing style may have influenced our results. To reduce the influence of team strategy, however, we have sampled matches over a 5-yr time frame. Second, we were unable to obtain kinetic characteristics of the registered header events. Nevertheless, we did use markers of field dimensions to estimate the length of the ball's flight course, providing some information regarding impact. This was recorded through our video analysis tool, associated with good to excellent registration accuracy. Third, because of limited availability of recordings of female national teams, a limited sample of matches was available to investigate sex differences, hence limiting statistical power of sex comparisons. Last, this study reflects heading during matches, not including heading exposure at training sessions. This leaves unexplored a potentially considerable source of heading exposure, of which quantification could be an important target for future research. Strengths of this study include the comprehensive registration of header events at the level of individual players, reports on maximum match exposure, and involving in elite players of adolescent to adult age, including male and female players.

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PERSPECTIVE

The potentially cumulative long-term impact of heading on the brain is hard to determine prospectively, and consequently, there is little high-quality research available (11–14). Because of the present study provides quantifications of real-life exposure to heading based on full-time match play, it is highly informative for current discussions on policy changes regarding the role of heading in football. For example, our results infer that 61%–63% of mean and maximum match exposure involves ball flight courses longer than 10 m, representing headers with relatively high impact. Likewise, keeper kicks and corner kicks account for 24% of mean and 26% of maximum match exposure. Consequently, game changes that ban heading of balls directly from keeper kicks and corner kicks may be able to considerably reduce heading exposure. Our results also indicate that some studies investigating the acute effects of heading on the brain have used dosages (e.g., 20 headers per player in 10 min) (18,19) that may be (too) high when considering our quantifications of maximum heading exposure (10.6 headers per match). The present findings of this study may therefore feed future prospective studies with real-life quantifications of heading exposure in elite football.

The authors would like to thank Roel Liège (video analyst at the Royal Netherlands Football Association (KNVB)) for his collaboration in developing the registration tool. The authors also wish to thank all video examiners for watching the recordings of matches to register the characteristics of heading events: Maria van Kortenboef, Roy Waalboer, Jos Bolt, René ten Broeke, Michael Jansen, Hans Mewiss, and Siebe van der Gun. This research was supported by the KNVB. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. Results of the present study do not constitute endorsement by the American College of Sports Medicine.

E. G. is employed as sports medicine physician at the medical center of the KNVB.

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