

ORIGINAL ARTICLE

Head impact exposure in youth football—Are current interventions hitting the target?

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Restrictions on heading in youth football have been implemented in some countries to limit head impact exposure. However, current interventions remain poorly guided by evidence. Our objective was to quantify heading exposure in youth football, assessing the effects of sex and age. Football matches played during an international youth football tournament with no heading restrictions were directly observed, including players from both sexes (11–19 years). The elite senior level was included for comparison, using video analysis. All heading events were registered, classified, and assigned to individual players. Heading rates were calculated for each sex and age group. We observed a total of 267 matches, corresponding to 4011 player hours (1927 player hours for females, 2083 player hours for males). Males headed more frequently than females (2.7 vs 1.8 headers/player hour; $P < .001$). Heading rates increased with age (ANOVA, $P < .001$), approaching the elite senior level for players 16 years and older. There was substantial variation within teams for all age and sex groups, with the widest range (1–18 headers) observed for girls aged 19. Girls younger than 12 years had the lowest exposure, with an average of <2 players per team heading the ball, each with 1–2 headers. In conclusion, age and sex influence head impact exposure in youth football, and warrants careful consideration when introducing injury prevention measures. Males are more frequently exposed than females, heading rates increase with age, and there is substantial variation between players. Heading is a rare event in the youngest age groups, especially among females.

KEYWORDS

concussion, epidemiology, repetitive, soccer, subconcussive, TBI

1 | INTRODUCTION

Repetitive head impacts are common in football due to the sport's unique feature of purposeful heading of the ball with the unprotected head. This element of the game remains controversial, as the potential associations with long-term neurological consequences are still unsettled.^{1,2} Nevertheless, even though heading is normally asymptomatic and rarely causes concussion,^{3–6} there is evidence to

suggest that cumulative heading exposure may lead to brain alterations in adults^{7–10} and affect cognitive function in adolescents.^{11,12} As a result, rule changes have been implemented by US Soccer to restrict heading behavior in youth football, aiming for primary prevention of head injuries. More specifically, heading the ball is banned for players until the age of 11, while limiting the number of headers until the age of 13.¹³ However, although well intended, such initiatives are poorly supported by evidence.

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Importantly, little is known about which factors influence head impact exposure in youth football. Based on a study on female youth players, Harriss et al¹⁴ found that the number of purposeful headers increased with age. Chrisman et al¹⁵ suggested that also sex may play a significant role. Both studies, however, were careful to emphasize the limited generalizability of their conclusions, mainly due to small sample sizes and homogenous populations.^{14,15} In addition, these studies were conducted in North America, and potential differences in playing styles between countries might further limit the external validity of their findings. Providing more accurate data on heading exposure, and how this may be influenced by age and sex, is key to assess risk. Furthermore, such data will help guide much-needed prospective studies on the effects of repetitive head impacts in youth football.

Norway Cup is the world's largest international youth football tournament,¹⁶ currently played with no heading restrictions. Including thousands of players, from teams of both sexes and across several age groups, the setting is ideal to assess differences in heading exposure. Thus, the primary aim of this study was to quantify heading exposure in youth football, assessing the effects of sex and age. As a secondary aim, we wanted to assess the incidence of head impact incidents carrying a high risk of acute head injury, and compare it to the elite senior level.

2 | METHODS

2.1 | Study design and participants

This study was based on direct observation of football matches played during an international football tournament, during the summer of 2018 in Oslo, Norway. Norway Cup is the world's largest football tournament for children and adolescents aged 10 to 19 years old, with nearly 30 000 players

participating over the course of 7 days.¹⁶ Out of nearly 2000 teams, most are from Norway, but teams from all over the world are participating. There are separate classes for male and female players, as well as for different age groups, including under-12 (U-12), U-13, U-14, U-15, U-16, U-17, U-18, and U-20. Standard match durations differ between age groups: U-12 and U-13 play 2 × 15 minutes, U-14 and U-15 play 2 × 20 minutes, U-16 and U-17 play 2 × 25 minutes, and U-18 and U-20 play 2 × 30 minutes. There are seven players per team for U-12 and U-13, nine players per team for U-14, and eleven players per team for U-15 and older. A convenience sample of matches from every age group from both sexes was included (Table 1).

In addition, the study included video observation of a random selection of 10 matches each from the female and male Norwegian premier leagues (Toppserien and Eliteserien) during the 2018 season; matches at this level have a standard duration of 2 × 45 minutes. These were added to include a professional/semi-professional senior level for comparison, observed from TV video recordings.

The Ethics committee at the Norwegian School of Sport Sciences approved the study. The study was observational and did not involve registering any sensitive personal information. Furthermore, as registered head impact exposure was not linked to any other personally identifiable information, player consent was not deemed necessary.

2.2 | Registration of head impact exposure

A group of trained research assistants observed the matches, with one observer present per match. Before the match started, the sex, age group, and nationalities of the teams were noted. All heading events in each match were then registered and classified as short or long headers. This was done based on the observer's subjective interpretation of the impact forces involved for the player. Short headers were defined as

TABLE 1 Number of observed matches, player hours, heading events, and head impact incidents according to age and sex during an international youth football tournament in Norway

Level	Boys				Girls			
	Matches (n)	Player hours	Headers (n)	Incidents (n)	Matches (n)	Player hours	Headers (n)	Incidents (n)
U-12	16	112	138	0	12	84	53	0
U-13	33	231	423	2	28	196	178	0
U-14	21	252	562	0	12	144	77	1
U-15	17	249	565	0	14	205	293	0
U-16	10	183	432	1	12	220	411	1
U-17	18	330	1079	3	12	220	495	0
U-18	6	132	405	0	14	308	536	1
U-20	12	264	855	4	10	220	534	2
Senior*	10	330	1127	9	10	330	886	6

*Senior level was observed from TV video recordings from the Norwegian premier leagues (Toppserien and Eliteserien), and included for comparison.

lower-grade impacts based on the distance of the incoming ball and a seemingly low force when heading; long headers were defined as higher-grade impacts based on a combination of a relatively longer distance and higher force when heading. Each event was assigned to an individual player by the number and color of his or her jersey. Headers were also classified based on the player's position on the pitch when the event occurred (defense, midfield, or attack) and according to the player's position in the center or in one of the side corridors (right or left), thereby dividing the pitch into nine equal zones.

In addition to purposeful headers, incidents thought to carry a high risk of head injury were registered, based on the following criteria: (a) the player appeared to be hit in the head, neck or face, (b) the match was interrupted by the referee, and (c) the player remained lying down on the pitch for more than 15 seconds. The same definition of head impact incidents was used by Andersen et al^{17,18} and Straume-Næsheim et al^{19,20} in previous studies.

To validate direct observation as a method, we included a subset of 24 Norway Cup matches that were broadcast on commercial television. For these matches, there were two independent observers present, in addition to one observer registering events through systematic video analysis (used as reference). This was done in order to assess: (a) the inter-rater reliability and (b) the sensitivity of direct observation for identifying heading events.

2.3 | Statistical analyses

For each sex and age group, the total number of observed player hours was calculated as the number of observed matches multiplied by the standard number of players on the pitch multiplied by the standard match duration. Heading rates (short, long and total) were calculated for each sex and age group as the average number of headers per player hour. To evaluate the distribution of heading exposure between players within teams, we also calculated the number of events per player for each match. Intraclass correlation coefficients (one-way random effects) were calculated to express inter-rater reliability. SPSS version 24 (IBM SPSS Statistics, IBM Corporation) was used for statistical analyses.

3 | RESULTS

We observed a total of 267 matches, corresponding to 4011 player hours, 124 matches for females (1927 player hours) and 143 matches for males (2083 player hours). In total, we registered 9049 headers, 3463 for females and 5586 for males. Table 1 shows an overview of the number of matches, player hours and heading events for the different age groups. Overall, males headed more frequently than females, with 2.7 headers per player hour for males and 1.8 for females (independent samples *t* test, $P < .001$). As shown in Table 2,

heading rates also differed between age groups (ANOVA, $P < .001$). Of the 247 tournament matches observed, 84% were played by Norwegian teams only, while 16% involved at least one team from another country.

Heading exposure for each player differed substantially within and between teams, with shifting distributions by age for both sexes (Figure 1). The most common location for heading events on the pitch was the central corridor, especially the central midfield (Figure 2), with the same pattern observed across all age groups for both sexes.

Throughout the youth football tournament, we observed a total of 15 head impact incidents, corresponding to an incidence of 4.5 (95% CI 2.6-7.2) incidents per 1000 player hours. For the matches on the elite senior level, the incidence was 22.7 (95% CI 13.2-36.7) events per 1000 player hours. Table 1 shows the number of incidents for each sex and age group.

Based on the 24 broadcast matches observed by two independent observers, the intraclass correlation coefficient was 0.99 (95% CI 0.98-1) for the total number of headers, 0.89 (95% CI 0.76-0.95) for short headers, and 0.85 (95% CI 0.67-0.94) for long headers. Compared to systematic video analysis, direct observation had a sensitivity of 91% for identifying heading events.

4 | DISCUSSION

This is the first study to investigate heading behavior in youth football in a large, heterogeneous cohort. Our results showed that male players consistently headed the ball more frequently than female players, and that heading rates increased gradually with age for both sexes. Importantly, as current restrictions target players 12 years old or younger, we document that heading the ball was a rare phenomenon in the youngest age groups, especially among girls. Not until teams started playing on full-sized pitches (U-15 and older) did we observe any notable increase in total heading exposure, gradually approaching the elite senior level (Figure 1). Furthermore, there was substantial variation in heading rates between players; some players hardly ever headed the ball, while a minority headed more frequently.

4.1 | Heading exposure in youth football

Our finding that heading rate increased with age is in line with that of Harriss et al.¹⁴ In their study on three female teams from three age levels (U-13 to U-15), they found that age had a significant effect on heading behavior. We show how that this also applies to males, as well as over a wider range of age. However, our rate of 1006 headers per 1000 player hours in the same age group as that studied by Harriss et al¹⁴ was more than 10-fold higher than theirs (74 per 1000 player hours). Lynall et al²¹ investigated head impact biomechanics in 19-year-old female collegiate players, and reported 7.16

TABLE 2 Heading rates (with 95% CI) by age and sex during an international youth football tournament in Norway. Rates are expressed as the average number of headers per player per hour

Level	Boys			Girls		
	Short headers	Long headers	Total headers	Short headers	Long headers	Total headers
U-12	1.0 (0.7-1.2)	0.3 (0.2-0.4)	1.2 (0.9-1.6)	0.5 (0.4-0.7)	0.1 (0.0-0.2)	0.6 (0.4-0.8)
U-13	1.3 (1.1-1.5)	0.6 (0.4-0.7)	1.8 (1.6-2.1)	0.8 (0.6-0.9)	0.1 (0.0-0.2)	0.9 (0.7-1.1)
U-14	1.5 (0.8-2.8)	0.8 (0.6-1.0)	2.2 (1.9-2.6)	0.5 (0.3-0.7)	0.2 (0.0-0.3)	0.6 (0.3-0.9)
U-15	1.6 (1.3-1.9)	0.7 (0.5-0.9)	2.3 (2.0-2.5)	1.1 (0.8-1.3)	0.4 (0.2-0.6)	1.4 (1.1-1.7)
U-16	1.7 (1.3-2.2)	0.6 (0.3-1.0)	2.4 (1.8-3.0)	1.5 (1.2-1.7)	0.4 (0.2-0.7)	1.9 (1.5-2.3)
U-17	2.1 (1.6-2.6)	1.2 (0.9-1.4)	3.3 (2.7-3.9)	1.7 (1.3-2.0)	0.6 (0.4-0.8)	2.3 (1.8-2.7)
U-18	1.7 (0.9-2.4)	1.4 (1.1-1.7)	3.1 (2.2-4.0)	1.3 (0.9-1.6)	0.6 (0.4-0.8)	1.9 (1.4-2.3)
U-20	1.9 (1.4-2.3)	1.4 (1.0-1.7)	3.2 (2.8-3.7)	1.7 (1.1-2.2)	0.8 (0.5-1.1)	2.4 (1.7-3.2)
Senior*	0.9 (0.7-1.1)	2.5 (2.1-3.0)	3.4 (2.8-4.0)	0.8 (0.6-0.9)	1.9 (1.7-2.2)	2.7 (2.4-3.0)

*Senior level was observed from TV video recordings from the Norwegian premier leagues (Toppserien and Eliteserien), and included for comparison.

head impacts per 90 minutes played (approx. 4800 per 1000 player hours), close to double the rate observed in our study (2427 per 1000 player hours). A key difference, however, is that they used skin-patch accelerometers to count the number of impacts. Employing a 10 g threshold, they classified anything above as a head impact, without secondary verification of events. As wearable sensor systems have several limitations,²² false-positive events in particular,²³ it is difficult to compare these numbers directly to ours. Chrisman et al¹⁵ used accelerometers, combined with visual verification, on a sample of 46 male and female youth players (11-14 years), and concluded that both age and sex seemed to have a significant influence on the variations they observed in head impact exposure; our data confirm this finding.

In addition to inherent differences between methods and low sample sizes, selection bias related to teams and playing styles are likely to have played a role in the above-mentioned studies; this is supported by our data showing substantial variation between matches within each age group (Figure 1). Previous studies have also shown that exposure varies between player positions.^{6,21} Based on our findings, we are not able to confirm this directly, as we did not collect data on player position, but only on pitch area. These showed that most heading events occurred in the central corridor (Figure 2), consistently across sex and age groups, suggesting that players in central positions are more exposed than players on the flanks.

4.2 | Head impact incidents

Regarding the head impact incidents, we remain careful to interpret these data, due to the low absolute number in the different sex and age groups (Table 1). Also, although such events are believed to carry a high risk for acute head injury, we did not gather any information on clinical outcomes. However, we do note that such incidents were relatively rare compared to the number of headers seen during regular game

play (approx. 2 incidents per 1000 headers). Furthermore, head impact incidents were fivefold more frequent at the elite senior level than at the youth level. The incidence we observed at the elite senior level was comparable to previously reported data from Andersen et al,¹⁸ using the same definition of head impact incidents. Analyzing the mechanisms of head injuries in youth football, as well as their clinical outcome, should be the subject of future studies.

4.3 | Methodological considerations

The main strength of our study is its large sample size, including both sexes over a wide range of age groups. Additionally, collecting the data during a limited time period in the same tournament setting ensures that the data can be directly compared between the different groups. Furthermore, as the tournament includes a diverse group of teams from different areas and nations, this increases the external validity of our findings. Lastly, as demonstrated through video validation, direct observation proved well suited to detect heading events.

We acknowledge several study limitations. First, using direct observation we were unable to obtain kinetic measures of individual impacts. To compensate, we classified heading events into “long headers” and “short headers” based on the observer's subjective interpretation. Despite acceptable inter-rater reliability, how this classification translates into actual accelerative forces is unknown. Second, we only included matches. Variations in head impact exposure during practices should also be explored. Third, other factors might have influenced our results, such as field conditions and style, level and intensity of play. As an example, most of the matches observed during Norway Cup were played on natural grass, some on relatively hard turfs; this was further exacerbated by a hot and dry summer in 2018. Whether this could interfere with more technical play on the ground, leading to more physical or aerial play, is unknown. For comparison,

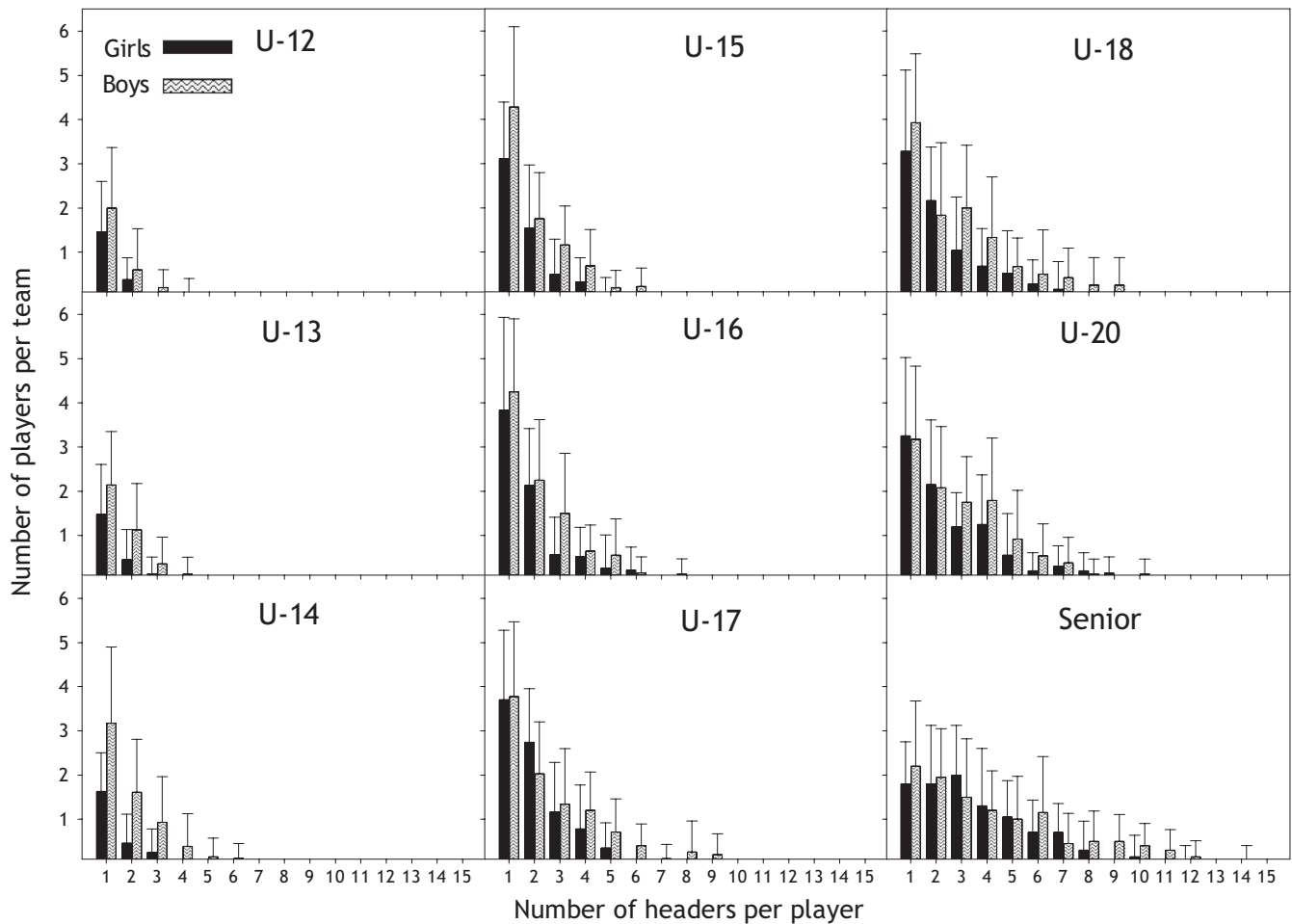


FIGURE 1 Distribution of headers within teams by sex and age groups during an international youth football tournament in Norway. Numbers are presented on a match basis as the average number of headers (\pm SD) per player per team. The elite senior level is included for comparison, based on numbers from the Norwegian premier leagues for men and women. Values exceeding 15 headers per player are excluded, comprising five players from the senior level and one player from girls U-18

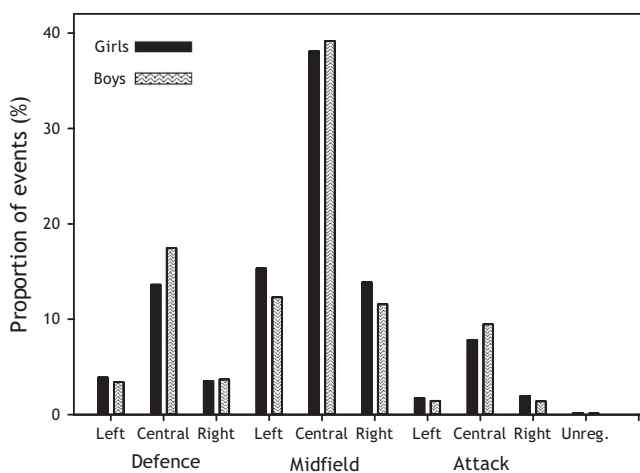


FIGURE 2 Pitch location of heading events during an international youth football tournament in Norway

we included the elite senior level from the Norwegian premier leagues, which is mostly played on artificial turf. We observed that their total heading rates were slightly higher

than for the U-20 level, but noted a higher proportion of long headers. We do not know if this is related to any of the above-mentioned factors. Lastly, sometimes younger players (and, on rare occasions, entire teams) play with an older age group, usually if they are particularly skilled. This happens relatively infrequently, but we were unable to account for it. In summary, however, it seems unlikely that any of these limitations undermine our main conclusions.

5 | PERSPECTIVE

This study demonstrates large variations in head impact exposure in youth football, demonstrating how age and sex are significant influencing factors. Our findings have several theoretical and practical implications. As previous biomechanical studies have also shown sex differences in head impact acceleration when heading the ball, attributed to, for example, neck strength and head-neck segment mass,^{24,25} the risk profiles between sexes may indeed be inherently

different. Thus, factors such as sex and age warrant careful consideration when planning and conducting studies on the link between repetitive head impacts in football and their potential neurological consequences. To prevent head injuries, it seems unlikely that a one-size-fits-all approach is satisfactory, and current interventions seem to target age groups where heading the ball is a rare phenomenon. Heading restrictions might miss the target, and future initiatives should be informed by scientific evidence—not by public opinion.

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