



## Article

# Preparedness during Head Impacts in Intercollegiate Men's and Women's Soccer Athletes

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**Abstract:** Research in hockey has found that preparedness and activity alter head impact magnitudes. It is unknown if similar occurrences take place in soccer. Therefore, our study purpose was to determine differences in the magnitudes and frequencies of head impacts due to sex and preparedness. Sixteen female (age:  $19 \pm 1.05$  years, height:  $163.68 \pm 5.03$  cm, mass:  $61.36 \pm 4.99$  kg) and 14 male (age:  $20 \pm 1.07$  years, height:  $180.34 \pm 5.58$  cm, mass:  $74.357 \pm 8.64$  kg) Division III intercollegiate soccer players were included in this study. The independent variables were sex and preparedness (anticipated with good body position, anticipated with poor body position, and unanticipated). xPatch sensors (X2 Biosystems, Seattle, WA, USA) applied over the participants' right mastoid processes for practices and games provided the frequency and biomechanics of all of the head impacts over 10 g. A total of 860 female and 870 male impacts were verified and coded by preparedness and activity during 1182 female (IR = 727.58, CI = 678.95–776.21) and 801 male (IR = 1086.14, CI = 1013.97–1158.32; IRR = 1.49, CI = 1.36–1.64) exposures. The interaction between sex and preparedness was significant for the combined dependent variables (multivariate  $F_{6,3442} = 3.67$ ,  $p = 0.001$ ,  $\eta_p^2 < 0.01$ ). Male and female intercollegiate soccer players, although exposed to different frequencies of head impacts, sustained similar magnitude impacts to the head within the preparedness categories. Training interventions should aim at improving technique while sustaining impacts as both sexes often received impacts while unprepared.

**Keywords:** magnitude; frequency; linear acceleration; rotational acceleration



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## 1. Introduction

Head impacts in sport are an increasing concern due to the potential of neurocognitive degenerative diseases from head injuries sustained while participating in sport [1]. Soccer is a compelling area for studying head impacts since the rules are identical between males and females and multiple studies have investigated head impacts in soccer players at various competitive levels [2–7]. Due to the contact nature of soccer, both male and female athletes sustain head impacts during participation, especially during games [8]. Long-term neurocognitive consequences have been found from repetitive head impacts during soccer participation in several studies [9–16]. Therefore, studying head impact biomechanics in soccer athletes is important.

Sex and whether the participant is prepared for impact or not may be important factors to consider when exploring head impact biomechanics and subsequent injury risk. Previous work in soccer [8,17], ice hockey [18], and lacrosse [19] has determined that male players sustain more head impacts than female players. Preparedness for impact has been linked to impact magnitude in youth hockey players with higher head accelerations occurring when players were not prepared for impact [20]. Stronger necks have been shown to reduce accelerations of the head, changes in head velocity, and head displacement in National

Football League players [21]. Therefore, it is postulated that anticipation for impact may reduce head impact severity since striking players were more prepared and better braced during impact which resulted in less violent impacts [22]. Indeed, greater anticipatory neck activation has been shown to decrease head accelerations in male and female athletes [23]. However, whether collegiate football players were prepared for impact or not did not factor into head impact severity [24]. Increased impact frequency and magnitude have been linked previously to a higher risk of head injury [25], thus stressing the importance of studying head impact biomechanics.

To date, no literature has examined the effect of preparedness on impact magnitudes in soccer. Therefore, the purpose of this study was to measure the magnitude and frequency of impacts to the head in male and female soccer players across preparedness (anticipated with good body position, anticipated with poor body position, and unanticipated). Our findings could ultimately have an influence on how soccer techniques are taught or have implications for rule enforcement. We hypothesized that unanticipated impacts would have higher magnitudes and that male soccer players would receive more impacts as well as having higher magnitudes of impact than their female counterparts.

## 2. Materials and Methods

### 2.1. Participants

In our study, 30 athletes from two National Collegiate Athletic Association (NCAA) Division III (DIII) soccer teams volunteered to participate. We successfully recruited 16 female (age =  $19 \pm 1.05$  years, height =  $163.68 \pm 5.03$  cm, mass =  $61.36 \pm 4.99$  kg) and 14 male (age =  $20 \pm 1.07$  years, height =  $180.34 \pm 5.58$  cm, mass =  $74.357 \pm 8.64$  kg) intercollegiate soccer players. During this study, the women's team participated in 28 games and 52 practices while the men's team had 21 games and 44 practices.

### 2.2. Instrumentation

All of the players wore xPatch sensors (X2 Biosystems, Seattle, WA, USA) during both practices and games during the fall season. The xPatch sensors continuously measured three axes of linear acceleration as well as three axes of angular velocity [7] which provided peak linear accelerations (PLAs) above 10 g with peak rotational accelerations (PRAs) and impact locations. We set the recording threshold to 10 g as impacts below 10 g are typically associated with the activities of daily living [26]. Although the xPatch has been shown to drastically overestimate the magnitudes of head impacts, it is more accurate and has less field research limitations than other products that were available for measuring head impact biomechanics in non-helmeted athletes at the time of data collection [27]. We also used the head impact magnitude data from the xPatch to make comparisons between two groups that were both using the xPatch as has been carried out previously [7]. Data were uploaded using the Head Impact Monitoring System (X2 Biosystems, Seattle, WA, USA) software.

### 2.3. Procedures

The study was approved by the host institutional review board, and the participants provided written consent prior to participation. Before practices and games, the xPatch sensors were removed from the docking station, turned on, and then applied to adhesive patches. The sensors were then adhered to the skin over the participants' right mastoid processes. We tracked every xPatch application during the course of the season to accurately calculate athlete exposures. Once practices or games were completed, the devices were placed back on the docking station to charge prior to the next event. Upon the end of practices or games, the data were then uploaded to the Head Impact Monitoring System (X2 Biosystems, Seattle, WA, USA) using a tablet computer (Hewlett-Packard, HP TouchSmart tm2, Palo Alto, CA, USA).

Each game and practice was recorded with the time and date stamped on the film. Researchers analyzed the film from all of the practices and games and coded each head

impact that could be viewed on film [28] that was clearly caused by an impact to the head. Video-verified impacts were then coded for preparedness. We defined preparedness for our study by one of three options: the impact was anticipated with good body positioning (knees and hips flexed, feet shoulder width apart, and drove through the contact), anticipated with poor body position, and unanticipated [29].

#### 2.4. Statistical Analysis

We calculated incidence rates (IRs) and incident rate ratios (IRRs) per 1000 athlete exposures with respective 95% confidence intervals (CIs) [30] for all three preparedness options between the two sexes using Microsoft Excel (Microsoft, Inc., Redmond, WA, USA). The Statistical Package for the Social Sciences (IBM SPSS, version 26, International Business Machine Corporation, Armonk, NY, USA) was used to determine the impact of sex and preparedness on the combined dependent variables (linear and rotational accelerations). We set an alpha value of 0.05 *a priori*. We computed Bonferroni post-hoc tests for significant interactions to determine where statistical differences existed.

### 3. Results

A total of 1681 head impacts could be verified during the season, with 842 in men during 21 games and 44 practices (801 total exposures; IR = 1086.14, CI = 1013.97–1158.32) and 839 impacts in women during 28 games and 52 practices (1182 total exposures; IR = 727.58, CI = 678.95–776.21; IRR = 1.49, CI = 1.36–1.64). The frequencies across sex and preparedness can be seen in Table 1. The overwhelming majority of the impacts occurred when the participants anticipated the contact in good body positioning.

**Table 1.** Head impact frequencies across preparedness levels.

Preparedness Level	Men's Soccer	Women's Soccer
Anticipated, with good body position	624 (74%)	730 (87%)
Anticipated, with poor body position	182 (22%)	81 (10%)
Unanticipated	36 (4%)	28 (3%)
Total	842 (100%)	839 (100%)

PLAs and PRAs across sex and preparedness levels can be found in Table 2. The interaction between sex and preparedness was significant for the combined dependent variables (multivariate  $F_{4,3348} = 3.86$ ,  $p = 0.004$ ,  $\eta_p^2 = 0.005$ ). Follow-up ANOVAs revealed significant interactions between sex and preparedness for rotational ( $F_{2,1675} = 3.50$ ,  $p = 0.03$ ,  $\eta_p^2 = 0.004$ ) but not linear ( $F_{2,1675} = 1.87$ ,  $p = 0.15$ ,  $\eta_p^2 = 0.002$ ) accelerations. Post-hoc test results can be found in Table 3. Unanticipated impacts produced lower PLAs than anticipated with good ( $p = 0.01$ ) or poor ( $p = 0.03$ ) body positioning in women. We also found higher PRAs when impacts were unanticipated compared to anticipated with good body positioning ( $p < 0.001$ ) in women.

**Table 2.** Head impact magnitudes across preparedness levels.

Preparedness Level	Men's Soccer		Women's Soccer	
	PLA	PRA	PLA	PRA
Anticipated, with good body position	17.14 ± 12.70	2616.53 ± 2749.29	22.07 ± 12.07	4533.83 ± 3249.59
Anticipated, with poor body position	16.53 ± 9.51	2689.64 ± 2840.96	22.33 ± 13.20	4045.61 ± 3205.56
Unanticipated	16.26 ± 8.92	2607.72 ± 2267.26	15.56 ± 5.95	2669.99 ± 2493.70
Total	16.97 ± 11.93	2631.96 ± 2747.95	21.88 ± 12.08	4424.49 ± 3239.56

**Table 3.** Post-hoc testing results.

PLA (g)	Preparedness (1)	Preparedness (2)	Mean Difference (1–2)	<i>p</i> Value	95% Confidence Interval for Mean Difference
Men’s Soccer	Anticipated, with good body position	Anticipated, with poor body position	0.61	1.00	−1.81, 3.03
	Anticipated, with good body position	Unanticipated	0.88	1.00	−4.04, 5.81
	Anticipated, with poor body position	Unanticipated	0.27	1.00	−4.97, 5.51
Women’s Soccer	Anticipated, with good body position	Anticipated, with poor body position	−0.26	1.00	−3.63, 3.10
	Anticipated, with good body position	Unanticipated	6.52	0.01 *	0.98, 12.05
	Anticipated, with poor body position	Unanticipated	6.78	0.03 *	0.48, 13.08
PRA (rad/s <sup>2</sup> )					
Men’s Soccer	Anticipated, with good body position	Anticipated, with poor body position	−4188.76	1.00	−38,846.86, 30,469.34
	Anticipated, with good body position	Unanticipated	504.99	1.00	−70,011.98, 71,021.97
	Anticipated, with poor body position	Unanticipated	4693.75	1.00	−70,348.62, 79,736.13
Women’s Soccer	Anticipated, with good body position	Anticipated, with poor body position	27972.49	0.49	−20,208.06, 76,153.04
	Anticipated, with good body position	Unanticipated	106789.68	<0.001 *	27,565.20, 186,014.16
	Anticipated, with poor body position	Unanticipated	78817.18	0.11	−11,372.52, 169,006.89

\* *p* < 0.05.

#### 4. Discussion

We sought to quantify head impacts by the frequency and magnitude in women’s and men’s collegiate soccer players during a season across different preparedness levels. Similar to previous studies [8], we found that men’s soccer players received a higher frequency of impacts than women’s soccer players. The reasons for the difference in head impact frequency between the sexes remain unknown and they are an important area for future research.

To our knowledge, only two previous studies have examined the effects of preparedness on head impacts in sport [20,24]. Our frequency results are different from previous research investigating the effects of head impact preparedness with youth hockey players [20], but similar to the results of college football players [24]. When comparing our results, the men were in a good body position 74% of the time and the women were in a good body position 87% of the time, substantially more than only 47% of the time for youth ice hockey players [20]. The women only received unanticipated impacts 3% of the time while the men received a slightly larger proportion of unanticipated impacts (4%). In comparison, youth hockey players received unanticipated impacts at a much higher rate (15%) [20]. When considering impact magnitude, previous research found significantly higher magnitudes when head impacts were unanticipated in youth hockey players [20]. While there were no pairwise differences between our men’s soccer players based on preparedness, our women’s players’ accelerations were higher when impacts were anticipated.

The inconsistencies in findings could be due to the differences between hockey and soccer. Hockey is played on ice where much faster player speeds can be achieved. We speculate unanticipated contact did not happen often in the current study since soccer fields are much larger than ice hockey rinks. Furthermore, ice hockey pucks are also much smaller

and likely move faster than soccer balls, thus making unanticipated impacts more likely in ice hockey compared to soccer. However, it remains unknown as to why males have a higher percentage of unanticipated impacts when compared to their female counterparts. During women's soccer play, head impact accelerations were lower when unanticipated compared to anticipated. We believe this happened due to most high acceleration impacts occurring during competitive headers which were anticipated and included body-to-body contact.

Soccer skill development and training sessions should focus on spatial awareness instruction to ensure a low number of unanticipated head impacts during soccer participation. Improving purposeful heading techniques and reducing player-to-player head contact could benefit soccer athletes by reducing the frequency and magnitude of head impacts. Programs exist in youth football that have shown promise for reducing player head impact frequency and magnitude [31]. Based on the success of these programs, similar specific youth soccer programs can be developed that focus on the awareness of head impacts and teaching proper heading techniques, as well as focusing on the reduction of player-to-player impacts during soccer participation.

There are limitations that are important to disclose in regards to our study. We collected data from NCAA Division III soccer players from only two teams at one institution. Generalizations to other populations should be cautioned against. Future studies should examine the effects of preparedness in other levels of competitive soccer and in other sports such as rugby. In addition, playing style could alter the results. For example, some teams may use different player formations with more or fewer players at a certain position on the field at one time. Therefore, additional teams with different playing styles should be studied. The xPatch sensor has measurement limitations that are important to consider [27]. However, we have no reason to believe the measurement error was different between the sexes or levels of preparedness. Future studies should include newer technology that has improved measurement accuracy.

## 5. Conclusions

Men sustained head impacts at a slightly higher rate than women. Intercollegiate soccer players of both sexes, although exposed to different frequencies of head impacts, sustained similar magnitude impacts to the head within the preparedness categories. Surprisingly, anticipated head impacts had higher magnitudes compared to unanticipated impacts for women. Training interventions should aim at improving technique when sustaining impacts as both sexes received impacts while unprepared.

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