Journal of Athletic Training 2018;53(1):000–000
doi: 10.4085/1062-6050-90-17
© by the National Athletic Trainers' Association, Inc
www.natajournals.org

Linear Acceleration in Direct Head Contact Across Impact Type, Player Position, and Playing Scenario in Collegiate Women's Soccer

Jaclyn B. Caccese, PhD*; Lindsey C. Lamond, MS*; Thomas A. Buckley, EdD, ATC*; Joseph Glutting, PhD†; Thomas W. Kaminski, PhD, ATC, FNATA, FACSM*

*Department of Kinesiology and Applied Physiology and †School of Education, University of Delaware, Newark

Context: Heading, an integral component of soccer, exposes athletes to a large number of head impacts over a career. The literature has begun to indicate that cumulative exposure may lead to long-term functional and psychological deficits. Quantifying an athlete's exposure over a season is a first step in understanding cumulative exposure.

Objective: To measure the frequency and magnitude of direct head impacts in collegiate women's soccer across impact type, player position, and game or practice scenario.

Design: Cross-sectional study.

Setting: National Collegiate Athletic Association Division I institution.

Patients or Other Participants: Twenty-three collegiate women's soccer athletes.

Main Outcome Measure(s): Athletes wore Smart Impact Monitor accelerometers during all games and practices Impacts were classified during visual, on-field monitoring of athletic events. All direct head impacts that exceeded the 10g threshold were included in the final data analysis. The dependent variable was linear acceleration, and the fixed effects were (1) type of impact: clear, pass, shot, unintentional deflection, or head-to-head contact; (2) field position: goalkeeper, defense, forward, or midfielder; (3) playing scenario: game or practice.

Results: Shots ($32.94g \pm 12.91g$, n = 38, $P = .02$) and clears ($31.09g \pm 13.43g$, n = 101, $P = .008$) resulted in higher mean linear accelerations than passes ($26.11g \pm 15.48g$, n = 451). Head-to-head impacts ($51.26g \pm 36.61g$, n = 13, $P < .001$) and unintentional deflections ($37.40g \pm 34.41g$, n = 26, $P = .002$) resulted in higher mean linear accelerations than purposeful headers (ie, shots, clears, and passes). No differences were seen in linear acceleration across player position or playing scenario.

Conclusions: Nonheader impacts, including head-to-head impacts and unintentional deflections, resulted in higher mean linear accelerations than purposeful headers, including shots, clears, and passes, but occurred infrequently on the field. Therefore, these unanticipated impacts may not add substantially to an athlete's cumulative exposure, which is a function of both frequency and magnitude of impact.

Key Words: repetitive head impacts, subconcussive head impacts, impact exposure, concussions

Key Points

- Nonheader impacts resulted in higher mean linear accelerations than purposeful headers but occurred infrequently on the field.
- No differences were observed in peak linear accelerations across player position.
- Head accelerations did not differ between games and practices.

On average, a female collegiate soccer player experiences 2 to 7 head impacts during a game and 2 to 4 head impacts during a practice,[1–3] thereby accumulating hundreds of impacts over a season and thousands over a career.[4] Soccer heading is usually unremarkable in that it does not present with the typical signs and symptoms of concussion; thus, many experts have referred to soccer headers as *subconcussive head impacts*.[5] The repetitiveness and frequency of these subconcussive head impacts have raised concerns that heading may put players at increased risk for long-term neurologic deficits, such as cognitive impairments, functional changes in the brain, and increases in biochemical markers of brain damage.[5,6] However, the association between soccer heading and neurologic deficits is controversial; a number of studies described as showing impairments in brain function had various methodologic shortcomings and often included only active and former professional male soccer players.[5] Understanding the frequency and magnitude of head impacts in women's collegiate soccer players will provide more information regarding the cumulative exposure for an understudied population and may elucidate ways to mitigate head-impact exposure and increase sport safety.

Cumulative exposure is a function of both the number and magnitude of impacts. Greater cumulative exposure has been associated with cognitive decline,[4,7] microstructural white matter brain changes,[4,7] vestibular and ocular functional deficits,[8–10] and later-life cognitive, behavioral, and mood impairment.[11] Montenigro et al,[11] for example, showed a dose-response relationship between the cumulative head-impact index and the risk for later-life cognitive impairment, self-reported executive dysfunction, depression, apathy, and behavioral dysregulation. In an attempt to determine which modifying factors influence head-impact magnitude, multiple researchers have measured on-field impacts during American football competition and practice,[12] but only recently have investigators quantified head acceleration in soccer. Authors head-impact biomechanical studies in soccer reported that cumulative exposure was greater in collegiate female players than in high school female players,[2] headers from goal kicks and punts were of greater magnitude than those during other strategic scenarios,[13] unanticipated head impacts led to greater head accelerations than purposeful headers,[3,14] and comparisons of practices versus games and player positions varied across teams depending on the style and level of play.[3,15] However, how head accelerations differ across type of header and how type of header contributes to cumulative exposure are unknown. In soccer, purposeful heading can be used to pass, clear, or shoot the ball, and understanding how head accelerations differ across these types of headers may allow athletes to limit those that result in the highest cumulative acceleration (ie, frequency × magnitude). A laboratory-based study[16] using controlled ball projections indicated that head accelerations differed by the type of header. Similarly, in another laboratory-based study,[17] investigators found that various unintentional impacts, such as upper extremity–to-head and head-to-head contacts, differed in head acceleration. Therefore, the purpose of our study was to compare the frequency and magnitude of head impacts in National Collegiate Athletic Association Division I women's soccer athletes by impact type, player position, and playing scenario in an attempt to better understand the cumulative exposure of these athletes over the course of 1 season. Consistent with Withnall et al,[17] we hypothesized that head-to-head contacts would result in the highest linear accelerations. Furthermore, we compared player positions and games versus practices, because previously reported data were contradictory.

METHODS

Study Participants

Twenty-four National Collegiate Athletic Association Division I women's soccer student-athletes provided written informed consent (IRB 500033-2) to participate in this study before the start of their fall 2015 season. One athlete was removed from the study because of a season-ending injury, resulting in 23 student-athletes (age = 19.7 ± 1.2 years, height = 168.3 ± 4.2 cm, mass = 62.0 ± 4.5 kg) who completed the study. All participants were members of the women's soccer team and at least 18 years of age by the start of the season. Participants were excluded from a particular day's data collection if they were not active in that session, if they did not wear their headbands, or if they removed the headband during play and did not put it back on. A history of concussion did not exclude an athlete from data collection. Participants included in the analysis represented all playing positions (goalkeepers [3]), defenders [3], forwards [6], and midfielders [11], and each participant was categorized by her most frequently played position.

Instrumentation

The Smart Impact Monitor (SIM; firmware version 3.7; SIM-G, version 3.3; AP, version 0.9.150413; software, Triax Technologies, Norwalk, CT) was used to quantify head acceleration. The SIM contains a low-*g* and high-*g* triaxial accelerometer to measure linear accelerations and a gyroscope to measure the rotational velocity of the head. Linear accelerations measured by the SIM are transformed to the estimated center of gravity (CG) of the head through proprietary manufacturer software using the following transformation equation:

$$\overrightarrow{a_{CG}} = \overrightarrow{a_{SIM}} + \vec{\ddot{\theta}} \times \vec{d} + \vec{\dot{\theta}} \times (\vec{\dot{\theta}} \times \vec{d})$$

where $\overrightarrow{a_{CG}}$ is the linear acceleration of the head CG, $\overrightarrow{a_{SIM}}$ is the linear acceleration of the SIM, $\vec{\ddot{\theta}}$ is the rotational acceleration of the head, $\vec{\dot{\theta}}$ is the rotational velocity of the head, and $\vec{d}$ is the estimated distance vector from the SIM to the head CG based on the 50th-percentile male, which is consistent with other accelerometer technologies.[18] The authors of 2 validation studies have reported (1) the ability of the SIM to count the number of impacts with a peak resultant linear acceleration of 20*g*[19] and (2) the accuracy of the SIM.[20] The SIM was able to detect both short- (eg, 5-millisecond head-to-head or head-to-ground contact) and long-duration (eg, 40-millisecond ball-to-head contact) impacts.[19] Peak linear acceleration did not differ between an instrumented headform and the SIM at 30*g* or 50*g*, but at 80*g*, the SIM tended to overestimate the peak linear acceleration.[20] In addition to comparisons at each of the 3 energy levels, correlation coefficient results showed a strong positive relationship between the instrumented headform and the SIM for peak linear acceleration, with the Pearson $r > 0.9$.[20] Our SIM's threshold was set to 10*g*, which is consistent with previous head-impact biomechanics research, including several soccer head-impact–exposure studies.[3,14,21]

Each participant was assigned a SIM and a custom headband (Figure 1A) and was instructed on how to properly position the SIM. The headband, once fitted with the SIM, was positioned around the nuchal line, consistent with the manufacturer's recommendations (Figure 1B), and headband placement was verified by the research team at the start of each game or practice. During games and practices, the SIM-G recorded impacts and uploaded them to a cloud database, where the data underwent preliminary filtering to remove those impacts that the SIM-G did not detect as true impacts.

Procedures

During each game and practice, up to 4 researchers visually observed impacts on the field and manually recorded them on the sideline. Any impacts that were not visually observed on the field or were not direct head impacts were removed. At the end of each game or practice, all impacts recorded by the SIMs were downloaded and categorized by (1) impact type (Table 1), (2) player position (goalkeeper, defense, forward, midfield), and (3) playing scenario (game, practice). Impact data were filtered to remove all impacts that occurred before the start or after the

Online First

Figure 1. Smart Impact Monitor (firmware version 3.7; SIM-G, version 3.3; AP, version 0.9.150413; software, Triax Technologies, Norwalk, CT) with A, custom headband, and B, placement of the headband on the head.

end of the game or practice. One *athlete-exposure* (AE) represented 1 individual participating in 1 athletic session (game or practice).

Statistical Analysis

All direct head impacts that exceeded the 10*g* threshold and were visually verified on the sideline during both games and practices were included. Indirect impacts, such as body contacts and hard cutting, were excluded because of the difficulty of visual verification both on the field and during video analysis. Data were analyzed using a multilevel linear model. Multilevel models typically include both random and fixed effects.[22,23] The dependent variable was linear accelerations, and the number of impacts served as a random effect (intercept). All fixed-effects predictors were on the nominal level of measurement and were dummy coded. The fixed-effect predictors were (1) type of impact: clear, pass, shot, unintentional deflection, or head-to-head contact; (2) field position: goalkeeper, defense, forward, or midfielder; and (3) playing scenario: game or practice. Regression coefficients were modeled using the maximum likelihood estimation with variance components as the variance-covariance error structure. Significance was defined a priori at $P < .05$.

Reliability analyses were also conducted for both visual verification (total number of impacts) and sideline classification (type of impact). These were completed using films from 5 games, which were reviewed by 2 researchers. Intrarater agreement compared each rater with the real-time observed data. Interrater agreement compared the 2 raters using game video only. For intrarater agreement, intraclass correlation coefficients were converted to Fisher Z scores, averaged, and then converted back to intraclass correlation coefficients. Reliability analyses revealed that visual verification of impacts resulted in strong interrater (0.99) and intrarater (0.97) agreement. Sideline classification of impacts resulted in poor interrater (0.32) and moderate intrarater (0.64) agreement.

RESULTS

Twenty-three student-athletes completed the study, resulting in 961 AEs in the final analysis across 1 season of play (Figure 2). The SIMs recorded 10 270 impacts during play; 627 of these impacts (6.1%) were visually verified as direct head impacts by researchers and included in the final data analysis (Figure 3). An additional 59 impacts were visually observed and recorded by the researchers but were not recorded by the SIM. These

Table 1. Definitions for Impact Type

Type of Contact	Type of Impact	Description
Header	Clear	A deflection of the ball with no goal of gaining control simply to get the ball out of the area. Used mostly by defensive and midfield players on the defensive side of the field.
	Pass	Trying to gain control of the ball through heading by either trapping or passing to a teammate. Used mostly by midfielders and forwards in the upper defensive and offensive sides of the field.
	Shot	Heading the ball with the intention of scoring a goal. Used mostly by forwards and occurs within the goal box on the offensive side of the field.
Nonheader	Unintentional deflection	A head impact with the ball that was unexpected.
	Head to head	A collision with another's head (opponent, official, or teammate).

Online First

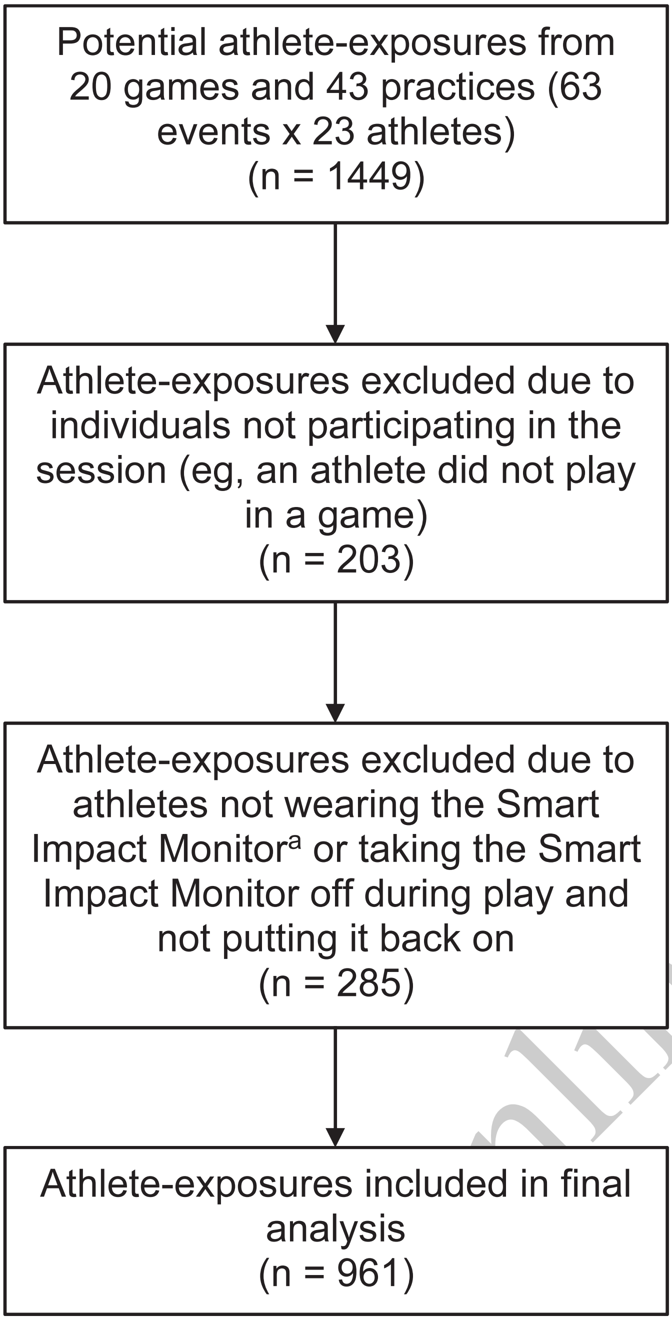

Figure 2. Flow chart of athlete-exposures excluded and included in final analysis. [a] Firmware version 3.7; SIM-G, version 3.3; AP, version 0.9.150413; software, Triax Technologies, Norwalk, CT.

impacts may have fallen below the 10*g* threshold or may not have been recognized as head impacts by the SIM. Head-to-ground, upper extremity–to-head, and lower extremity–to-head contacts were omitted because of the small number of occurrences. Descriptive statistics for the season are presented in Table 2.

Type of Impact

The fixed effects are presented in Table 3 and are represented by unstandardized β coefficients. The unstandardized coefficients describe how well each predictor (type of impact) estimates the dependent variable (peak linear acceleration) after controlling for all other predictors

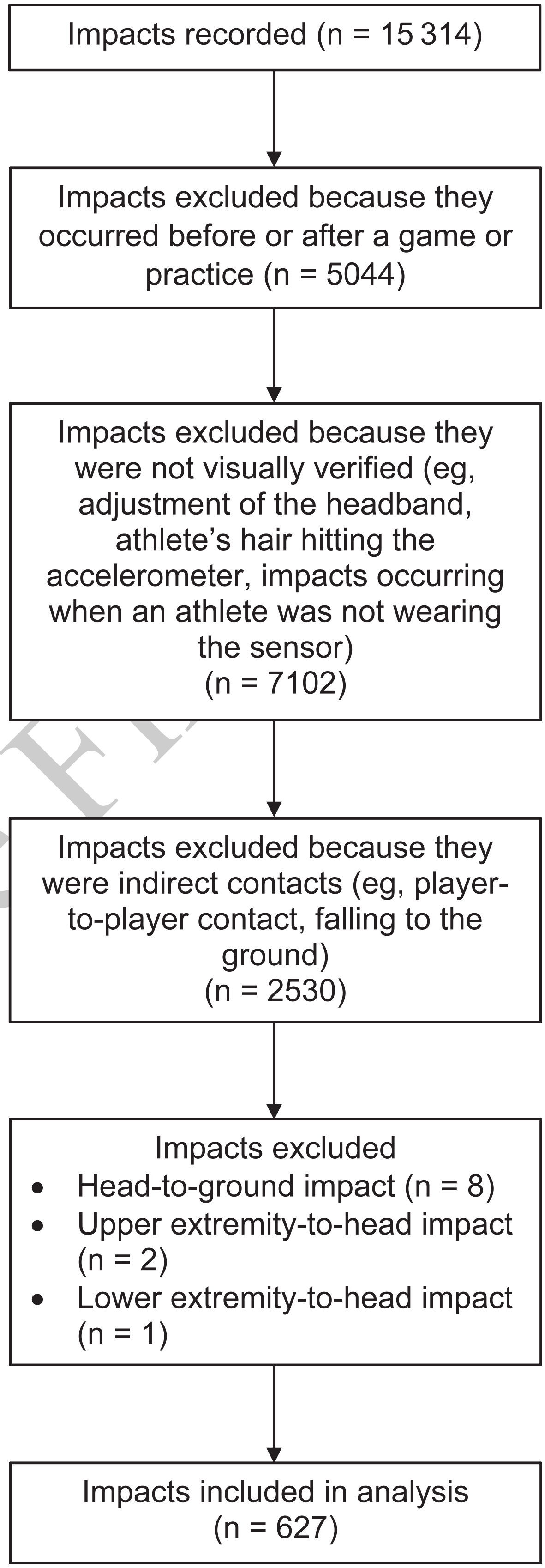

Figure 3. Flow chart of impacts recorded and analyzed according to exclusion and inclusion criteria.

Table 2. Descriptive Statistics of Impacts

	No.	Minimum, *g*	Maximum, *g*	Median, *g*	Mean ± SD, *g*	25th Quartile, *g*	75th Quartile, *g*	Impacts per 10 Athlete-Exposures
Season	627	10.16	160.60	23.28	28.28 ± 17.35	15.82	35.39	6.7
Games	443	10.63	102.23	24.57	29.29 ± 18.06	14.34	30.96	16.9
Practices	184	10.16	160.60	20.83	25.85 ± 15.19	16.28	36.54	2.6

in the analysis. Shots ($32.94g \pm 12.91g$, $P = .02$) and clears ($31.09g \pm 13.43g$, $P = .008$) resulted in higher mean linear accelerations than passes ($26.11g \pm 15.48g$). Head-to-head impacts ($51.26g \pm 36.61g$, $P < .001$) and unintentional deflections ($37.40g \pm 34.41g$, $P = .002$) resulted in higher mean linear accelerations than purposeful headers (ie, shots, clears, and passes). Impacts per 10 AEs were compared using rate ratios and are presented in Table 3.

Player Position

We found no differences in peak linear acceleration across player position (Table 4). Goalkeepers experienced only 4 head impacts, all unintentional deflections, over the course of the season. Impacts per 10 AEs were compared using rate ratios and are presented in Table 4.

Playing Scenario

Peak linear accelerations did not differ between games ($29.29g \pm 18.06g$) and practices ($25.85g \pm 15.19g$, $P = .09$; Table 5). Of the 627 impacts recorded, 443 (71%) occurred during games. Impacts per 10 AEs were compared using rate ratios and are presented in Table 5.

Interaction Effects

We explored all possible 2-way interaction effects. The only significant interaction effect was pass × games versus practices ($P = .004$), whereby passes during games resulted in greater head accelerations.

DISCUSSION

Understanding the frequency and magnitude of various types of purposeful headers and unanticipated head impacts may reveal ways to mitigate the cumulative exposure and increase soccer athletes' safety. Our primary finding was that nonheader impacts, including head-to-head impacts ($51.26g \pm 36.61g$, n = 13), and unintentional deflections ($37.40g \pm 34.41g$, n = 26) resulted in greater mean linear accelerations than purposeful headers, including shots ($32.94g \pm 12.91g$, n = 38), clears ($31.09g \pm 13.43g$, n = 101), and passes ($26.11g \pm 15.48g$, n = 451). These findings are consistent with those of Hanlon and Bir,[14] who reported that, at the youth level, nonheader impacts ($22.3g$) resulted in higher linear accelerations than purposeful headers ($20.4g$). At the collegiate level, Press and Rowson[3] observed that headers resulted in a linear acceleration of $25g \pm 17g$ and nonheaders resulted in an average range of $20g$ to $35g$, though this difference did not reach statistical significance. In addition, we noted large standard deviations within each header type (50%–100% of the mean magnitude of impact), suggesting that other factors, such as ball speed, neck strength, technique, and anthropometric properties, influenced linear acceleration during soccer heading.[24]

Although nonheader impacts, including head-to-head impacts and unintentional deflections, resulted in higher mean linear accelerations than purposeful headers, including shots, clears, and passes, nonheader impacts occurred infrequently (4%, rate ratio = 0.06) on the field. Therefore, these unanticipated impacts may not add substantially to an athlete's cumulative exposure, which is a function of both frequency and magnitude of impact. Combined, head-to-head impacts and unintentional deflections accounted for $1639g$ ($71.3g$ per athlete over the course of the season), which was less than 10% of the cumulative exposure. Conversely, passes (72% of all impacts), which had the lowest magnitude of impact, accounted for two-thirds of the cumulative exposure ($511.7g$ per athlete over the course of the season). Lipton et al[4] demonstrated white matter changes and poorer cognitive function in soccer players who self-reported an estimated >1800 headers over the previous year and suggested that repetitive heading was associated with these changes. However, they defined cumulative exposure only by the number of head impacts and did not include impact magnitude. Our data suggest that in women's collegiate soccer, the number of headers may serve as a surrogate for cumulative exposure, because cumulative head acceleration was driven largely by heading frequency, as opposed to impact magnitude.

Table 3. Means, Medians, and Results of Fixed Effects From Mixed Linear Model for Type of Impact (N = 627 Impacts)

Predictor	Value or Coding	No.	Impacts per 10 Athlete-Exposures (Rate Ratio)	Median	Mean ± SD, *g*	95% CI Lower Limit	95% CI Upper Limit	β (SE)[a]	*P*
Intercept								25.79 (1.12)	<.001[b]
Header impact	Pass	451	4.7 (1.00)	20.80	26.11 ± 15.48	24.67	27.54	Reference	
	Clear	101	1.1 (0.23)	29.71	31.09 ± 13.43	28.44	33.75	4.96 (1.85)	.008[b]
	Shot	38	0.4 (0.09)	29.97	32.94 ± 12.91	28.70	37.19	6.86 (2.87)	.02[b]
Nonheader impact	Head to head	13	0.1 (0.02)	35.34	51.26 ± 36.61	29.13	73.38	23.50 (4.65)	<.001[b]
	Unintentional deflection	24	0.3 (0.06)	22.74	37.40 ± 34.41	22.87	51.93	10.96 (3.49)	.002[b]

Abbreviations: CI, confidence interval; SE, standard error of the unstandardized coefficient.

[a] β, unstandardized β coefficient.

[b] Indicates difference ($P < .05$).

Online First

Table 4. Means, Medians, and Results of Fixed Effects From Mixed Linear Model for Player Position (N = 627 Impacts)

Predictor	Value or Coding	No.	Impact per 10 Athlete-Exposures (Rate Ratio)	Median, *g*	Mean ± SD, *g*	95% CI, *g* Lower Limit	95% CI, *g* Upper Limit	β (SE)[a]	*P*
Intercept								28.18 (1.54)	<.001[b]
Position	Goalkeeper (n = 3)	4	0.3 (0.04)	28.65	36.42 ± 20.49	3.81	69.02	8.69 (8.92)	.33
	Forward (n = 6)	84	5.5 (0.65)	22.27	25.91 ± 14.42	22.78	29.04	−1.66 (2.93)	.58
	Defense (n = 3)	173	12.2 (1.44)	24.44	27.80 ± 16.91	25.27	30.34	−0.41 (2.81)	.89
	Midfield (n = 11)	366	8.5 (1.00)	23.28	28.28 ± 18.08	27.10	29.64	Reference	

Abbreviations: CI, confidence interval; SE, standard error of the unstandardized coefficient.

[a] β, unstandardized β coefficient.

[b] Indicates difference (*P* < .05).

Previous comparisons of games versus practices and of player positions were inconclusive and varied across teams depending on the style and level of play[3,15] and coaching philosophies. For example, the number and intensity of heading-related practice drills would substantially influence practice exposure. The team we studied did not participate in any heading drills during the season, so it is not surprising that we reported 16.9 head impacts per 10 AEs in games and 2.6 head impacts per 10 AEs in practices, a 6.5-fold greater exposure to subconcussive impacts in games than in practices. No difference was evident in overall peak linear acceleration between games (29.29g ± 18.06g) and practices (25.85g ± 15.19g), possibly because most headers observed during practices occurred during intrateam scrimmages and were similar to those headers observed during games. In addition, we found that defenders (12.2 impacts per 10 AEs) and midfielders (8.5 impacts per 10 AEs) had the highest numbers of impacts, but head-acceleration magnitude did not differ across player position. A longitudinal study evaluating a variety of teams at a variety of levels of play is needed to identify the true differences in cumulative exposure across games, practices, and player positions.

We focused largely on cumulative exposure to repetitive head impacts during 1 season of collegiate women's soccer. Cumulative exposure, which can be defined as a function of frequency and magnitude of impact, has been associated with cognitive decline,[4,7] microstructural changes in brain white matter,[4,7] vestibular and ocular functional deficits,[8–10] and later-life cognitive, behavioral, and mood impairment.[11] However, it is still unclear if concussion risk and long-term risk can be quantified by cumulative exposure. In other words, we do not know if cumulative exposure puts an individual at greater risk for long-term problems than sustaining a single high-magnitude impact. However, Montenigro et al[11] showed a dose-response relationship between the cumulative head-impact index and the risk for later-life cognitive impairment, self-reported executive dysfunction, depression, apathy, and behavioral dysregulation. The cumulative head-impact index was calculated from a combination of years of athletic exposures in football and estimated head impacts received per season, based on data from published helmet-accelerometer studies that provided the frequency of head impacts per season by position and level of play.[11] These exploratory findings suggest that more research is needed regarding the effects of cumulative exposure on concussion risk and long-term risk.

Over the course of this study, 10 270 total impacts were recorded by the head accelerometers during play. A total of 627 direct head impacts were visually verified and included in the data analysis, leading to a 6% inclusion rate. This is a substantial limitation of head-accelerometer technologies in general, as noted by Press and Rowson,[3] who visually observed 1463 of the 17 865 total impacts recorded (an 8% inclusion rate), and it highlights the need for visual verification in head-impact–exposure studies. However, poor sideline interrater reliability (0.32) reflects disagreement among raters as to the type of impact. To reiterate, the main finding of our study was that nonheader impacts resulted in higher mean linear accelerations than purposeful headers but occurred infrequently on the field. Misclassifications of impacts occurred almost exclusively across types of purposeful headers (ie, shots, passes, and clears). Therefore, we do not believe that these misclassifications negate the conclusions presented herein.

We used the SIM, whereas other investigators have used different accelerometer technologies, such as the xPatch sensor (X2; Biosystems Inc, Seattle, WA)[3,21] and the HIT system (Simbex, Lebanon, NH).[14] Different accelerometer technologies have different associated errors,[25,26] and thus, we must be cautious when comparing studies. Cummiskey et al[26] evaluated 4 head-impact accelerometers (the HIT system, Shockbox [i1 Biometrics, Kirkland, WA], SIM, and xPatch) for their ability to detect impact, linear acceleration, and location. Of the 140 impacts delivered during

Online First

Table 5. Means, Medians, and Results of Fixed Effects From Mixed Linear Model for Playing Scenario (N = 627 Impacts)

Predictor	Value or Coding	No.	Impacts per 10 Athlete-Exposures (Rate Ratio)	Median, *g*	Mean ± SD, *g*	95% CI, *g* Lower Limit	95% CI, *g* Upper Limit	β (SE)[a]	*P*
Intercept								26.14 (1.51)	<.001[b]
Playing scenario	Game (n = 20)	443	16.9 (6.50)	24.57	29.29 ± 18.06	27.60	30.97	2.66 (1.57)	.09
	Practice (n = 43)	184	2.6 (1.00)	20.83	25.85 ± 15.19	23.64	28.06	Reference	

Abbreviations: CI, confidence interval; SE standard error of the unstandardized coefficient.

[a] β, unstandardized β coefficient.

[b] Indicates difference (*P* < .05).

testing, the SIM recorded all 140, with a root mean square error ranging from 12.97% to 74.68% depending on the location of the impact. Although the SIM recorded 100% of the controlled impacts in the laboratory, many extraneous impacts were recorded on the field, and 59 impacts were not registered by the SIM at all. This suggests that the exposure rate may be slightly (<2.5 impacts per player per season) higher than reported. Finally, Wu et al[25] demonstrated larger errors with tight-fitting elastic cap accelerometers than with instrumented mouth guards and mastoid process attachments; however, validation studies suggested that the SIM measured no difference in reported peak linear accelerations from an instrumented headform at 30*g* or 50*g*.[20] At 80*g*, the SIM overestimated peak linear accelerations. This is a limitation, but only 10 of the 627 impacts (1.6%) we recorded were greater than 80*g*.

Although head impacts in American football players have received considerable attention, other contact sports such as soccer have been studied infrequently. The current study improves our understanding of linear-acceleration exposure in collegiate women's soccer; yet it was limited to data obtained from 1 team across 1 fall season, and therefore the results should not be generalized to other levels of play, sexes, or seasons. We measured linear accelerations in collegiate women's soccer players and identified that purposeful contact with the ball resulted in lower linear accelerations but was more frequent than contact with another player or unintentional deflections, indicating that purposeful headers contributed more to cumulative head-impact exposure than did unintentional or unanticipated contact.

REFERENCES

1. Kaminski TW, Wikstrom AM, Gutierrez GM, Glutting JJ. Purposeful heading during a season does not influence cognitive function or balance in female soccer players. *J Clin Exp Neuropsychol*. 2007; 29(7):742–751.
2. McCuen E, Svaldi D, Breedlove K, et al. Collegiate women's soccer players suffer greater cumulative head impacts than their high school counterparts. *J Biomech*. 2015;48(13):3720–3723.
3. Press JN, Rowson S. Quantifying head impact exposure in collegiate women's soccer. *Clin J Sport Med*. 2017;27(2):104–110.
4. Lipton ML, Kim N, Zimmerman ME, et al. Soccer heading is associated with white matter microstructural and cognitive abnormalities. *Radiology*. 2013;268(3):850–857.
5. Tarnutzer AA, Straumann D, Brugger P, Feddermann-Demont N. Persistent effects of playing football and associated (subconcussive) head trauma on brain structure and function: a systematic review of the literature [published online ahead of print November 4, 2016]. *Br J Sports Med*. 2016. doi:10.1136/bjsports-2016-096593.
6. Maher ME, Hutchison M, Cusimano M, Comper P, Schweizer TA. Concussions and heading in soccer: a review of the evidence of incidence, mechanisms, biomarkers and neurocognitive outcomes. *Brain Inj*. 2014;28(3):271–285.
7. Davenport EM, Whitlow CT, Urban JE, et al. Abnormal white matter integrity related to head impact exposure in a season of high school varsity football. *J Neurotrauma*. 2014;31(19):1617–1624.
8. Kawata K, Tierney R, Phillips J, Jeka JJ. Effect of repetitive subconcussive head impacts on ocular near point of convergence. *Int J Sports Med*. 2016;37(5):405–410.
9. Kawata K, Rubin LH, Lee JH, et al. Association of football subconcussive head impacts with ocular near point of convergence. *JAMA Ophthalmol*. 2016;134(7):763–769.
10. Hwang S, Ma L, Kawata K, Tierney R, Jeka JJ. Vestibular dysfunction after subconcussive head impact. *J Neurotrauma*. 2017;34(1):8–15.
11. Montenigro PH, Alosco ML, Martin BM, et al. Cumulative head impact exposure predicts later-life depression, apathy, executive dysfunction, and cognitive impairment in former high school and college football players. *J Neurotrauma*. 2017;34(2):328–340.
12. Ahmadisoleymani SS, Yang J. American football helmet for preventing concussion, a literature review. *Procedia Manufacturing*. 2015;3(suppl C):3796–3803.
13. Caccese JB, Lamond LC, Buckley TA, Kaminski TW. Reducing purposeful headers from goal kicks and punts may reduce cumulative exposure to head acceleration. *Res Sports Med*. 2016;24(4):407–415.
14. Hanlon EM, Bir CA. Real-time head acceleration measurement in girls' youth soccer. *Med Sci Sports Exerc*. 2012;44(6):1102–1108.
15. Lynall RC, Clark MD, Grand EE, et al. Head impact biomechanics in women's college soccer. *Med Sci Sports Exerc*. 2016;48(9):1772–1778.
16. Shewchenko N, Withnall C, Keown M, Gittens R, Dvorak J. Heading in football. Part 1: development of biomechanical methods to investigate head response. *Br J Sports Med*. 2005;39(suppl 1):i10–i25.
17. Withnall C, Shewchenko N, Gittens R, Dvorak J. Biomechanical investigation of head impacts in football. *Br J Sports Med*. 2005; 39(suppl 1):i49–i57.
18. Camarillo DB, Shull PB, Mattson J, Shultz R, Garza D. An instrumented mouthguard for measuring linear and angular head impact kinematics in American football. *Ann Biomed Eng*. 2013; 41(9):1939–1949.
19. Oeur RA, Karton C, Hoshizaki TB. Impact frequency validation of head impact sensor technology for use in sport. Paper presented at: 34th International Conference on Biomechanics in Sports; July 18–22, 2016; Tsukuba, Japan:79–83.
20. Karton C, Oeur RA, Hoshizaki TB. Measurement accuracy of head impact monitoring sensor in sport. Paper presented at: 34th International Conference on Biomechanics in Sports; July 18–22, 2016; Tsukuba, Japan.
21. Chrisman SP, MacDonald CL, Friedman S, et al. Head impact exposure during a weekend youth soccer tournament. *J Child Neurol*. 2016;31(8):971–978.
22. Hox JJ. *Multilevel Analysis: Techniques and Applications*. Mahwah, NJ: Lawrence Erlbaum Associates; 2002.
23. Raudenbush SW, Bryk AS. *Hierarchical Linear Models: Applications and Data Analysis Methods*. 2nd ed. Thousand Oaks, CA: Sage Publications; 2002.
24. Caccese JB, Kaminski TW. Minimizing head acceleration in soccer: a review of the literature. *Sports Med*. 2016;46(11):1591–1604.
25. Wu LC, Nangia V, Bui K, et al. In vivo evaluation of wearable head impact sensors. *Ann Biomed Eng*. 2016;44(4):1234–1245.
26. Cummiskey B, Schiffmiller D, Talavage TM, et al. Reliability and accuracy of helmet-mounted and head-mounted devices used to measure head accelerations. *J Sports Eng Technol*. 2017;231(2):144–153.

Address correspondence to Jaclyn B. Caccese, PhD, Department of Kinesiology and Applied Physiology, University of Delaware, 540 South College Avenue, Newark, DE 19716. Address e-mail to jcaccese@udel.edu.

Online First