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Head Impact Exposure in Practices Correlates with Exposure in Games for Youth Football Players

Srinidhi Bellamkonda, M.S.¹, Samantha J. Woodward, M.S.¹, Eamon Campolettano, M.S.⁴, Ryan Gellner, B.S.⁴, Mireille E. Kelley, M.S.⁵, Derek A. Jones, M.S.⁵, Amaris Genemaras, Ph.D.², Jonathan G. Beckwith, M.S.², Richard M. Greenwald, Ph.D.², Arthur C. Maerlender, Ph.D.³, Steven Rowson Jr., Ph.D.⁴, Stefan M. Duma, Ph.D.⁴, Jillian E. Urban, Ph.D.⁵, Joel D Stitzel, Ph.D.⁵, and Joseph J. Crisco, Ph.D.¹

¹Bioengineering Laboratory, Department of Orthopaedics, The Warren Alpert Medical School of Brown University and Rhode Island Hospital, Providence, RI, USA

²Simbex, Lebanon, NH, USA

³Center for Brain, Biology & Behavior at University of Nebraska, Lincoln, NE, USA

⁴Department of Biomedical Engineering and Mechanics at Virginia Tech, Blacksburg, VA, USA

⁵Virginia Tech-Wake Forest University School of Biomedical Engineering and Sciences, Winston-Salem, NC, USA

Abstract

This study aimed to compare head impact exposures between practices and games in football players ages 9 to 14, who account for approximately 70% of all football players in the US. Over a period of two seasons, 136 players were enrolled from three youth programs and 49,847 head impacts were recorded from 345 practices and 137 games. During the study, individual players sustained a median of 211 impacts per season, with a maximum of 1226 impacts. Players sustained 50th (95th) percentile peak linear acceleration of 18.3 (46.9) g, peak rotational acceleration of 1305.4 (3316.6) rads^{-2} , and HITsp of 13.7 (24.3), respectively. Overall, players with a higher frequency of head impacts at practices recorded a higher frequency of head impacts at games ($p < 0.001$, $r^2 = 0.52$) and players who sustained a greater average magnitude of head impacts during practice also recorded a greater average magnitude of head impacts during games ($p < 0.001$). The youth football head impact data quantified in this study provides valuable insight into the player exposure profile, which should serve as a key baseline in efforts to reduce injury.

Keywords

linear acceleration; rotational acceleration; HIT system; impacts per practice; impacts per game

Correspondence Address: Joseph J. Crisco, Ph.D. Bioengineering Laboratory, Department of Orthopaedics Alpert Medical School of Brown University and Rhode Island Hospital CORO West, Suite 404, 1 Hoppin Street, Providence, Rhode Island, 02903 Phone : 401-444-4231, Fax : 401-444-4418, joseph_crisco@brown.edu.

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INTRODUCTION

Sports-related brain injuries, especially mild traumatic brain injury (mTBI), have garnered public attention and led to questions on how to make sports safer for the athletes.^{1–6} Bryan et al. estimates an annual occurrence of 1.1 to 1.9 million sports- and recreation-related concussions in children under the age of 18 in the US.⁷ While concussions are defined as a transient disruption of brain function due to a direct or indirect biomechanical force to the brain, studies suggest subconcussive head impacts may lead to pathophysiological changes in brain function without the manifestation of concussion symptoms.⁸ Therefore, documenting exposure (magnitude, frequency, and location) of subconcussive head impacts remains an important challenge.

Injury statistics from the Consumer Product Safety Commission reported football (touch and tackle) to have the highest number of head injuries due to helmet to helmet collisions, and collision with a goal post, with some of these injuries being fatal.⁹ Initial studies quantifying the frequency and severity of head impacts in football have focused primarily on high school and collegiate players.^{10–14} However, there has been a recent increase in studies investigating head impact exposure in football players under the age of 14, who account for over 70% of the 5 million athletes participating in organized football each year.^{15–18} Daniel et al. reported an increase in magnitude and frequency of impacts as youth players progressed to higher age and weight groups.¹⁵ Their findings were consistent with other studies on age groups 7–8, 9–13, 14–18 and 18–22.^{19–23} While the relationship between an increase in the frequency of high magnitude impacts with age has previously been established, it is pertinent to understand the trends at the youth level, to gauge the cumulative effect of the head impacts that the players sustain throughout their career.

Recent studies have compared head impact exposure of practice and game sessions,^{13,21,22} citing specific drills as having the highest rate of high magnitude impacts during practice.^{24,25} Wong et al. also studied exposure in practices and games for individual players in the youth population, but the study was limited by a small sample size and the binary switch based impact sensor (Shockbox Impact Alert Sensor, Impakt Protective Inc., Canada) utilized in the study excluded all head impacts below 30 g,¹⁸ which would eliminate over 50% of the impacts reported by previous studies.^{12–15,21,26–29} Currently with no rigorous tool to diagnose, treat and prevent concussions in football, reducing head impact exposure is potentially an effective approach for reducing the risk of brain injury in this population.^{30–33}

In addition to limiting contact during practice and changing practice structure, the relationship between head impact exposure at practices, and games for individual players at the youth level is also important but remains unknown. Analyzing the correlation between practices and games for individual players can provide more specifics on play technique and behavior, which may help identify specific players who could be at a higher risk for injury. Moreover, identifying player exposure profile could then allow coaches to implement strategies to reduce head impacts, ultimately mitigating the risk of injury. Therefore, this study aimed to investigate if individual players who sustain higher frequency of impacts per practice also sustain higher frequency of impacts per game and if individual players who

receive greater magnitude impacts during practice also receive greater magnitude impacts during games.

METHODS

After IRB approval, 74 players (mean 10.9 ± 1.2 years) were recruited from three youth programs (A, B and C) in 2015 and 96 players (mean 11.8 ± 1.3 years) were recruited from the same youth programs in 2016. Informed assents were obtained from players, and informed consents were obtained from their parents. Thirty-four players contributed to both years of the study. Players from program A ($n = 59$) participated in an unaffiliated league, players from program B ($n = 51$) participated in the American Youth Football (AYF) league and players from program C ($n = 26$) participated in the Pop-Warner league. Data collection was conducted throughout two seasons (2015 and 2016) during practices ($n = 345$) and games ($n = 137$).

Players wore either Riddell Revolution or Speed football helmets that were instrumented with the Head Impact Telemetry (HIT) System (Simbex, Lebanon, NH) that is part of the [Riddell] Sideline Response System (SRS) (Riddell, Elyria, OH). The HIT System measures linear acceleration of the center of gravity (CG) of the head, estimates rotational acceleration at the CG, and impact location on the helmet.^{11,29,34–36} The HIT system includes a sideline receiver unit, laptop with radio receiver and sensor unit for each helmet. The sensor unit is comprised of an array of non-orthogonal single-axis accelerometers, and when a single accelerometer exceeds 9.6 g during an impact, the impact is recorded over a 40-millisecond duration, including 8-milliseconds of pre-trigger data. The HIT system has been validated and the errors associated with the system have been reported extensively.^{15,37–39}

A session was defined as either a practice or a game. Practices were defined as sessions with a potential of contact to the head in which players wore helmets and pads. This definition included practices with helmet only and/or helmet and shoulder pads only sessions, which accounted for less than 0.8% of all practice impacts. Games included both competitions and scrimmages. Participation in a session was defined as a player receiving at least one impact for a given practice or game session.¹¹

The biomechanical data consisted of head-impact events that exceeded a peak resultant linear acceleration of 10 g. In this study, as in our previous studies, the peak resultant linear acceleration threshold of 10 g was implemented to eliminate head accelerations from non-injurious acceleration events (e.g. running, jumping, etc.).^{11,40} Video footage was collected at all sessions and researchers verified impacts above 60 g through video identification to avoid overestimation of the frequency of these higher magnitude impacts. Events recorded outside of an organized team sessions (game, practice, or scrimmage) and during water breaks were removed before analysis. Other recorded events that do not represent typical rigid body head acceleration patterns, such as those from a helmet being kicked or thrown, were also excluded from the dataset.³⁵

Five measures of head impact frequency were analyzed for each player: *number of practice impacts*, the total number of head impacts a player sustained during all practices; *number of*

game impacts, the total number of head impacts a player sustained during all games; *impacts per season*, the total number of head impacts for a player during all team sessions in a single season; *impacts per practice*, the average number of head impacts a player sustained during practices; and *impacts per game*, the average number of head impacts a player sustained during games.¹⁰ For all exposure measures, each impact was analyzed individually but the cumulative number of impacts, for players that participated in both years of the study, was averaged to report impacts per season. Each individual player's distribution of peak linear acceleration (g), peak rotational acceleration (rad s^{-2}), and peak HITsp were quantified by the 50th and 95th percentile value for each session type. HITsp is a non-dimensional measure of head impact severity.⁴¹ It is measured by transforming the computed head impact measures into a single latent variable using Principal Component Analysis and applying a weighting factor based on impact location.⁴¹

Data was analyzed using Matlab (Mathworks, Natick, MA), and exported to SigmaPlot (Systat Software, Chicago, IL) and GraphPad (GraphPad Software, San Diego, CA) for statistical analysis. Measures of impact frequency and magnitude were expressed as median values and [25% - 75%] inter-quartile range, as the study measures were not normally distributed, according to the Shapiro-Wilk Normality test. Correlations in head impact exposure measures between practices and games were assessed using linear regression analysis and outliers were not removed. Wilcoxon signed rank tests were performed to analyze differences in acceleration values between practices and games. Differences in impacts per season across programs were examined using a Kruskal-Wallis one-way ANOVA on ranks.

RESULTS

A total of 49,847 head impacts were recorded over the two seasons within 482 sessions (345 practices and 137 games). Players participated in a median of 19.0 [15.0–23.3] practices per season and 9.0 [7.0–10.0] games per season.

The median total number of head impacts per season received by an individual player was 211.0 [122.3–371.5] with a maximum of 1225.5 impacts. The median total number of impacts sustained per season during practices was 132.0 [69.5–235.5], with a maximum of 660.0 impacts. The median total number of impacts sustained per season during games was 71.3 [36.0–139.0], with a maximum of 581.5 impacts. For individual sessions, the median number of impacts received by a player was 7.2 [4.6–10.5] per practice and 7.9 [4.6–15.4] per game.

The number of head impacts per practice had a significant positive correlation ($p < 0.001$, $r^2 = 0.52$) with the number of head impacts per game for individual players (Figure 1). All three programs had a significant ($p = 0.003$, $r^2 = 0.63$ (A), 0.38 (B), 0.31 (C)) relationship between impacts per practice and impacts per game across individual players (Figure 2) even though the total number of impacts varied significantly ($p < 0.0001$) among the different programs (Figure 3).

Study-wide, 10.0% of head impacts ($n = 4959.0$) were greater than 40 g, 2.8% of impacts ($n = 1397.0$) were greater than 60 g, and 0.8% of impacts ($n = 414.0$) were greater than 80 g. By location, 51.6% of head impacts were to the front of the helmet, 20.1% were to the back of the helmet, 18.6% were to the side of the helmet and 9.7% were to the top of the helmet. The exposure data for right and left head impact locations did not differ significantly ($p = 0.346$), so they were combined and reported as head impacts to the side.

Although the median difference was minimal (0.20 g), players experienced significantly lower median linear acceleration during practices than games ($p = 0.039$, Table 1). Players also experienced impacts with significantly lower estimated median rotational acceleration and 95th percentile peak HITsp during practices than games ($p = 0.023$, $p = 0.036$ and median difference = 47 rad s⁻², 0.7). There were no significant differences between practices and games for 95th percentile peak linear acceleration ($p = 0.833$), 95th percentile peak rotational acceleration ($p = 0.109$), or 50th percentile peak HITsp ($p = 0.133$) (Table 1). There was, however, a significant positive correlation ($p < 0.001$) within the study population between practices and games for the 50th and 95th linear acceleration, rotational acceleration and HITsp (Figure 4 & Table 1). Correlations between impacts per season and the 95th percentile peak linear acceleration, rotational acceleration and HITsp were not as strong ($r^2 = 0.07$, 0.04 and 0.09 respectively) as the correlations for the 50th and 95th linear acceleration, rotational acceleration and HITsp.

DISCUSSION

The purpose of this study was to quantify head impact exposure in youth football players ages 9–14 and analyze the relationships between impact frequency and magnitude per individual player by session type. From two years of data, we found that a higher number of impacts per practice correlated with a higher number of impacts per game for individual players. Additionally, greater magnitude impacts during practices were also correlated with greater magnitude impacts during games for individual players. There was, however, no correlation between head impact frequencies and head impact magnitudes. Collectively, these findings indicate that there is a correlation in head impact exposure between practices and games, but that players who experience the largest magnitude head impacts do not necessarily receive the most frequent head impacts.

Overall, the median number of head impacts recorded per player was 7.2 per practice and 7.9 per game. These values are within the range of values reported by Cobb et al. (9.7 per practice, 11.3 per game), Young et al. (9.0 per practice, 11.0 per game), Munce et al. (9.0 per practice, 12.0 per game) and Daniel et al. (6.7 per practice, 5.8 per game) at the youth level.^{15,16,19,20} Our results were also consistent with studies that reported an increase in head impact exposure with age and level of play (youth to high school, high school to college).^{15,23,42} The frequency of impacts by session for players in this youth study was less than the range of impacts reported in previous studies for high school (5.3–9.4 impacts per practice and 13.0–15.5 impacts per game) and collegiate players (6.3–13.2 impacts per practice and 14.3–24.2 impacts per game).^{10,14,21,22,28,43} Cobb et al., postulated that this increase in impact frequency from youth to high school and high school to collegiate level was due to an increase in size, strength, and speed of the players.¹⁷ It is also interesting to note that even

though the total number of head impacts significantly differed across the three observed youth programs (Figure 3), the positive correlation of impact frequency between practices and games remained across the three youth programs (Figure 2).

In considering impact magnitudes, the median linear acceleration for practices (18.2 g) and games (18.4 g) measured in this study were similar to those reported by Cobb et al. (18.0 g in practices, 19.0 g in games), Young et al. (17.0 g in practices, 17.0 g in games) and Munce et al. (19.9 g in practices, 20.9 g in games) at the youth level.^{16,19,20} While the median linear and rotational acceleration values of the current study (18.3 g, 1305.4 rads⁻²) were in approximately the same range as that of the high school population (20.5–27.1 g, 942.0–1468.6 rads⁻²) and the collegiate population (20.5–32.0 g, 981.0–1400.0 rads⁻²), the 95th percentile magnitude values (46.7 g, 3316.6 rads⁻²) of this study were lower when compared to their high school and collegiate counterparts (53.7–62.7 g, ~4378 rads⁻²).^{11–13,21,22,26,44,45} This indicates that the youth players in this study population are sustaining lower high magnitude impacts. Other researchers have hypothesized that youth players may be at a greater risk of injury compared with high school and collegiate players because they possess lower body mass and neck strength.^{46–49} However, our study protocol did not control for factors such as player mass, neck strength, and preparedness. It is also important to appreciate that wearable sensors, such as the HIT system used in this study, measure resultant head accelerations and not the impact force.

While evaluating the correlation of the frequency and magnitude variables between practice and game for individual players provided a unique opportunity to identify player profile, the study also has several limitations. A player was designated as participating in a session only if the player received at least one head impact above 10 g. This definition is enabled using exposure sensors such as the HIT system, which allows us to specifically study head impact exposure instead of the often-used metric of athletic exposure (AE).⁵⁰ Our previous studies have shown that AE can be a very poor measure of head injury risk. It was shown that players with the same risk of head injury as defined by AE (e.g. 50) had dramatically different numbers of head impact that varied from approximately 200 to 1400. Impacts lower than 60 g did not go through the same validation process because of the challenges involved in identifying impacts (e.g. low resolution, occluded views, etc.).⁵¹ Additionally, impacts above 60 g are more readily verified, whereas lower magnitude impacts are difficult to locate on video and far greater in frequency. Players with elevated head impact exposure were included in the analysis, as they may offer better insight into players associated with high magnitude and/or frequency impacts. A more detailed behavioral analysis of these players may be warranted, as they may benefit from interventions in attempts to reduce head impacts. While player position has demonstrated to be a strong factor in head impact exposures with high school and collegiate population,^{10–14,22,50} it was not used as a factor to analyze impact exposure in this study because assigning a specific position to each youth player was challenging; majority of youth players in these programs participated in offense, defense, and special teams, including various positions within each unit.

Previous studies have attributed differences in head impact exposure among teams and programs to variations in style of play,^{52,53} practice drill implementation,²⁴ coaching style,⁵⁴ tackling style,^{55–57} difference in the number of players per team, or difference in league

rules.¹⁶ The study analysis presented herein did not control for these factors. However, the fact that the correlation in head impact exposures between practices and games persisted despite the variations in these factors suggest that a player's specific behavior may play a large role in their exposures. In that case, coaches being provided with resources to monitor head impact, and implement strategies to reduce head impact^{33,58} may be an efficient way of limiting impact exposure.

In conclusion, findings of this study suggest the frequency and magnitude of impacts that players sustain during practice have a positive association with impacts they sustain during games. Players who experience elevated magnitude and/or frequency of head impacts in practices also experience elevated magnitude and/or high frequency of head impacts in games. Ultimately, these findings, along with more data collection and analysis at the youth level, may give researchers an insight into players with tendencies for elevated head impact exposure. Understanding these associations should help in reducing the risk of brain injury in youth football.

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Figure 1. Impacts per game correlated linearly ($r^2 = 0.52$, $p < 0.001$) with impacts per practice for individual players. Each data point represents an individual player.

Figure 2.

Correlation between impact frequency per practice and per game for individual players did not differ significantly by program.

Figure 3. Distribution of total number of impacts per player per season differed substantially among the three youth programs.

Figure 4.

Positive significant correlation was found between head impacts during practice and games for median peak linear acceleration (g) (A), 95th percentile peak linear acceleration (g) (B), median peak rotational acceleration (rad s⁻²) (C), 95th percentile peak rotational acceleration (rad s⁻²) (D), median peak HITsp and (E), 95th percentile peak HITsp (F).

Table 1:

Linear regression analysis for games vs practice and study wide 50th and 95th percentile peak linear acceleration, peak rotational acceleration and peak HITsp for the season, practices and games.

		<u>Season</u>	<u>Practice</u>	<u>Game</u>	<u>Slope of best fit</u>	<u>p-value</u>	<u>r²</u>
50 th %	Linear Acc (g)	18.3[17.1–19.3]	18.2[16.6–19.4]	18.4[16.8–19.8]	0.54 ± 0.09	p < 0.001	0.21
	Rotational Acc (rad.s ⁻²)	1305.4[1188.2–1397.4]	1290.0[1151.0–1404.0]	1337.0[1217.0–1441.0]	0.79 ± 0.07	p < 0.001	0.46
	HITsp	13.7[13.2–14.2]	13.6[13.0–14.2]	13.9[13.1–14.5]	0.83 ± 0.08	p < 0.001	0.42
95 th %	Linear Acc (g)	46.9[40.5–52.5]	47.0[38.8–52.9]	46.5[40.8–54.1]	0.46 ± 0.06	p < 0.001	0.28
	Rotational Acc (rad.s ⁻²)	3316.6[2852.3–3664.9]	3187.0[2772.0–3658.0]	3278.0[2844.0–3920.0]	0.49 ± 0.09	p < 0.001	0.18
	HITsp	24.3[22.0–27.3]	24.1[21.4–27.2]	24.9[21.4–28.2]	0.60 ± 0.07	p < 0.001	0.34

Note. Results expressed as mean + SD. Results expressed as Median [25th–75th] percentile

* Symbolizes significance difference between accelerations at practice and games