

Head Impact Exposure in Youth Football Practice Drills

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ABSTRACT

The purpose of this study is to evaluate frequency and magnitude of head impacts in practice drills within a single youth football team. On-field head impact data were collected from 9 athletes (age = 11.1 ± 0.6 years, weight = 97.6 ± 12.2 lbs.) participating in an age and weight restricted youth football team for a single season. Head impact data were collected with the Head Impact Telemetry (HIT) System head acceleration measurement device. Video was recorded for all practices and games and video analysis was performed to verify head impacts and assign each impact to a specific drill. Drills were identified as: dummy/sled tackling, install, kickoff practice, Oklahoma, one-on-one, open field tackling, passing, position skill work, multi-player tackle, tackling drill stations, and scrimmage. Mixed effects linear models were fitted and Wald tests were used to assess differences in head accelerations and number of impacts. There were significant differences in mean linear ($p < 0.0001$) and rotational ($p = 0.003$) acceleration and number of impacts per player ($p < 0.0001$) among drills. Open field tackling drills had the highest median/95th percentile linear accelerations of 24.7g/96.4g and resulted in significantly higher mean head accelerations compared to several other drills. The multi-player tackling drill resulted in the highest head impact frequency of 6.6 impacts per player in a drill session. This study demonstrates the variability in head impact exposure among practice drills. These data, along with future research, may inform organizations on ways to structure their practice to limit high impact and high frequency drills and make sports safer for youth.

INTRODUCTION

Approximately 5 million athletes play organized football in the United States; 2,000 NFL, 100,000 college, 1.3 million high school, and 3.5 million youth (Powell and Barber-Foss 1999; Guskiewicz, Weaver et al. 2000; Daniel, Rowson et al. 2012). Despite making up the largest proportion of football athletes, youth football has seen declines in participation in recent years (SFIA 2013; SFIA 2015). Although several factors may be attributing to the decline in participation, concern over injuries, particularly concussion and the long-term side effects of repetitive head impacts, have been suggested as major factors (Institute 2014). However, youth football participation and long-term neurological deficits are still not well understood. A study by Stamm et al. demonstrated an association between involvement in tackle football prior to age 12 and cognitive impairment in former NFL players later in life, but a similar study by Solomon

et al. failed to find an association between participation in football prior to high school and later-life neurological deficits (Stamm, Bourlas et al. 2015; Solomon, Kuhn et al. 2016). Further research is necessary to better understand the long-term effects of exposure to repetitive head impacts. In particular, more head impact exposure data are needed in the youth football population. Although impact data from youth athletes are scarce, preliminary data suggest that youth football players sustain head impacts approaching the magnitude of high school and collegiate football players (Daniel, Rowson et al. 2012; Pellman, Lovell et al. 2006; Rowson, Broinson et al. 2009; Rowson, Goforth et al. 2009; Cobb, Urban et al. 2013). Additionally, a study of head impact exposure in youth football athletes aged 7-8 years showed that impacts greater than 80g were occurring during practices, not games (Daniel, Rowson et al. 2012).

In an effort to reduce risk of concussion and overall head impact exposure, some football organizations have taken steps to implement rule changes that affect practice structure. For example, in 2012 Pop Warner limited the amount of contact allowed at each practice and eliminated several full speed head-on blocking or tackling drills (2012). Cobb et al. studied the effect of limiting contact in practices in youth football by comparing one team that adopted the aforementioned practice limitations on contact and two teams that did not (Cobb, Urban et al. 2013). Players participating on the team with contact limitations had 37-46% fewer head impacts for the entire season than those on the teams that did not implement contact limitations (Cobb, Urban et al. 2013). Football organizations have also implemented educational programs such as the Heads Up Football program to train coaches on tackling technique, proper equipment fitting, and strategies to reduce player-to-player contact and concussion (Football ; Kerr, Yeargin et al. 2015; 2016). A study evaluating the effectiveness of the Heads Up Football program found that leagues implementing this program accumulated significantly fewer head impacts per practice compared to leagues that did not (Kerr, Yeargin et al. 2015).

These studies have shown that head impact exposure can be directly controlled by coaches, leagues, and organizations by adopting rules and regulations to limit contact or improve the quality of contact. However, it is yet to be determined how specific practice drills play a role in the head impact exposure measured on the field. The objective of this study is to evaluate the frequency and magnitude of head impacts in practice drills within a single youth football team through biomechanical data collection and detailed video analysis.

METHODS

On-field head impact data from athletes participating in a local youth football team were collected during one season of play. The study protocol was approved by the Wake Forest School of Medicine Institutional Review Board and participant assent and parental consent were properly acquired for participation in the study. The athletes enrolled in the study participate in a youth football league in which athletes are placed on teams based on age and weight requirements set by the national governing organization. The athletes evaluated in this study participated in a team with the age and weight requirements of 10 years old or younger with a maximum weight of 119 lbs. or 11 years old with maximum weight of 99 lbs.

Head impact data were collected by instrumenting the helmets of youth football players with the Head Impact Telemetry (HIT) System head acceleration measurement device during all preseason, regular season, and play-off practices and games. Each study participant was issued a

Riddell Speed helmet with the HIT System installed. The HIT System includes an encoder, which is an array of six spring-mounted single-axis accelerometers oriented normal to the surface of the head, a telemetry unit, data storage device, and battery pack. The encoder is designed to fit between the existing padding of a Riddell Speed helmet. The spring-mounted accelerometers allow the encoder to remain in contact with the head throughout the duration of a head impact, ensuring measurement of head acceleration, not helmet acceleration (Manoogian, McNeely et al. 2006). The data from the encoder are transmitted wirelessly via radio wave transmission to the sideline base unit. The data are then used to compute peak and resultant linear acceleration, estimated peak resultant rotational acceleration, location of impact, and other biomechanical indicators. The HIT System has been extensively described in previous literature and been found to reliably compute peak linear acceleration, peak rotational acceleration, and impact location (Beckwith, Greenwald et al. 2012; Broglio, Eckner et al. 2012).

Video was recorded for all practices and games and post-season video analysis was performed to remove false impacts (e.g. dropped helmet) and to record the name, start time, and end time for each drill to pair the video with the biomechanical data such that each head impact was identified as belonging to a specific drill. Drill names and descriptions were provided by the coaches for the team and were classified as: dummy/sled tackling, install, kickoff practice, multi-player tackle, Oklahoma, one-on-one, open field tackling, passing drill, position skill work, scrimmage, and tackling drill stations (Table 1).

Table 1: Descriptions of each drill classification

Drill	Description	Purpose
Dummy/Sled tackling	Players tackle dummy or sled	Reinforce wrapping while tackling and improve form for blocking
Install	Full 11-on-11 intra-team scrimmage	Within-team practice of offense and defense game strategy in a game-like situation
Kickoff practice	Special teams install	Practice alignment and responsibilities for different kickoff scenarios
Multi-player tackle	One offensive player versus two or three defensive players	Improve blocking/tackling form and technique and encourage athletes to move their feet
Oklahoma	Two vs. two or three vs. three tackling drill	Simulate game speed while working to improve blocking, running, and tackling technique in a confined space
One-on-One	One vs. one tackling drill with the two athletes starting less than 3 yards apart	Improve one-on-one tackling form and technique
Open Field Tackling	One vs. one tackling drill with the two athletes starting greater than 3 yards apart at an angle	Improve form and technique for tackling in full speed game-like situations
Passing drill	Athletes receive passes from coaches	Improving passing/catching skills and hand-eye coordination
Position Skill Work	Offense and defense skill-set specific drills	Practice offensive or defensive specific skills and game strategy
Scrimmage	Inter-team scrimmage with another team	Practice of offense and defense game strategy in a game-like situation between adjacent age and weight classified teams
Tackling Drill Stations	Separate team into smaller groups and complete a series of tackling drills.	Practice tackling drills in smaller groups with a higher coach to player ratio than whole team tackling drills

All verified head impacts collected over the season were used to quantify head impact exposure for all practice drills in terms of impact magnitude, frequency, and location. Mixed effects linear models were fitted and Wald tests were used to assess differences among drills in the associated linear and rotational accelerations and the number of impacts. We analyzed raw data to provide means of linear and rotational accelerations and analyzed log-transformed data to provide means of number of impacts; but also conducted interference on log-transformed acceleration data to confirm statistical significance. A Bonferroni correction was applied for all statistical tests to account for multiple comparisons and control the overall alpha level to be 0.05. All statistical analyses were performed using SAS software version 9.4 for Windows (SAS Institute Inc., Cary, NC, USA).

RESULTS

A total of 3,761 head impacts were recorded from 9 athletes during 36 practices and 11 games. Practices accounted for 2,171 (57.7%) head impacts and games accounted for 1,590 (42.3%) head impacts (Table A1). All athletes were monitored by a certified athletic trainer for signs and symptoms of concussion and no head impacts measured in this study resulted in a clinically diagnosed concussion. The average \pm standard deviation age and weight of the athletes on the team was 11.1 ± 0.6 years old and 97.6 ± 12.2 lbs., respectively. The distribution of the total number of head impacts experienced during a season among players was right skewed and ranged from 169 to 1003 head impacts, with a median value of 350. The distributions of head impact magnitudes varied among players with the 95th percentile linear acceleration ranging from 43.7g to 63.7g (Figures 1 and 2).

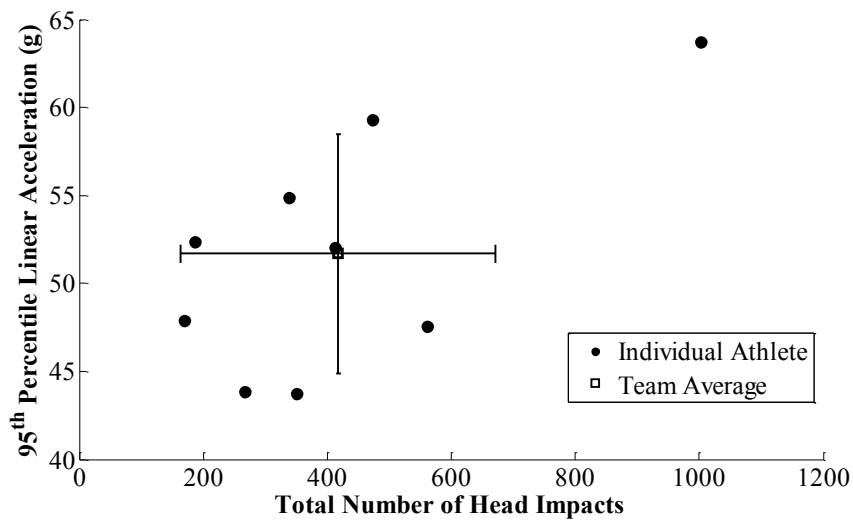


Figure 1: Athlete and team average 95th percentile linear acceleration vs. total number of impacts in season. Team average is shown with standard deviation error bars.

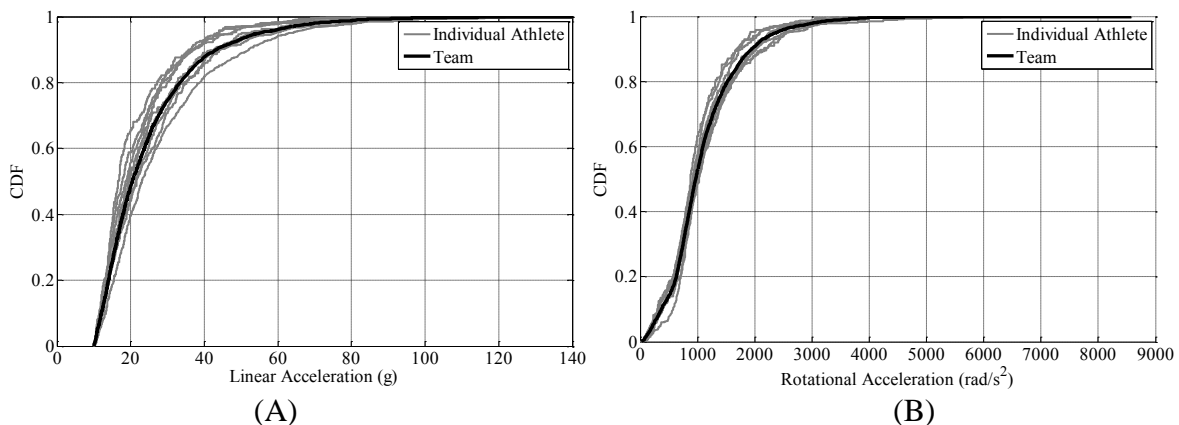


Figure 2: Cumulative distribution plots of (A) linear and (B) rotational acceleration for each athlete and the team.

The distribution of head impact magnitudes varied among practice drills (Figure 3). Additionally, head impact magnitude was not proportional to the frequency of head impacts for

each drill (Figure 4). A summary of impact frequency and impact magnitude for each drill is shown in Table A1. Open field tackling drills had median/95th percentile linear accelerations of 24.7/96.4g, which was the highest magnitude of all drills practiced by the team. Install was the most common drill with 1,217 impacts and had a median/95th percentile linear acceleration of 19.7/51.7g. The drills with the lowest magnitude head impacts were dummy/sled tackling, passing drills, and multi-player tackle.

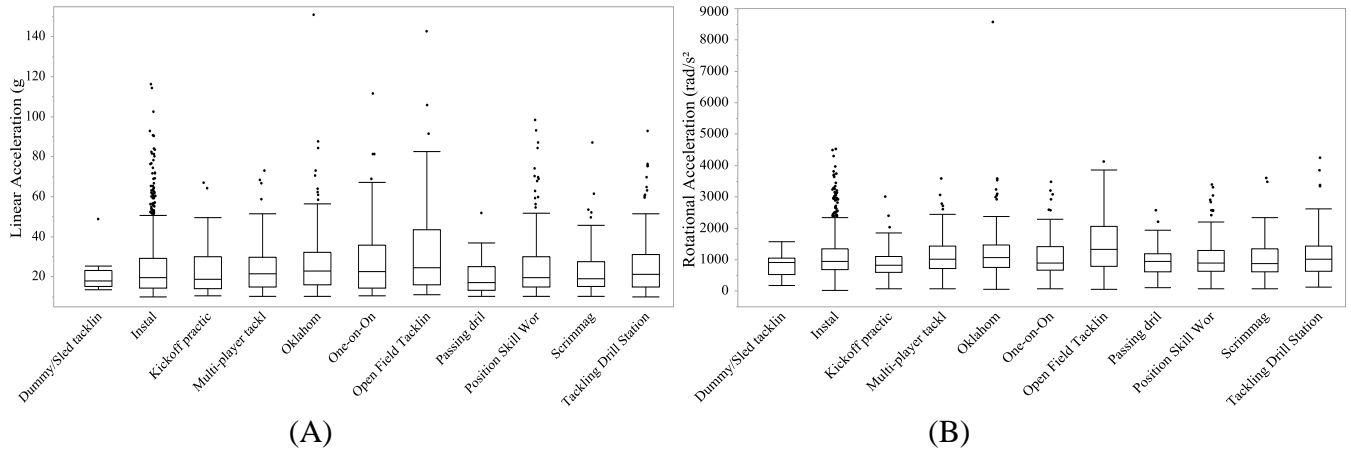


Figure 3: Distribution of (A) linear and (B) rotational acceleration for each of the practice drills.

■ Dummy/Sled tackling + Install △ Kickoff practice ▲ Multi-player tackle ◆ Oklahoma × One-on-One
 × Open Field Tackling ◇ Passing drill ○ Position Skill Work ● Scrimmage □ Tackling Drill Stations

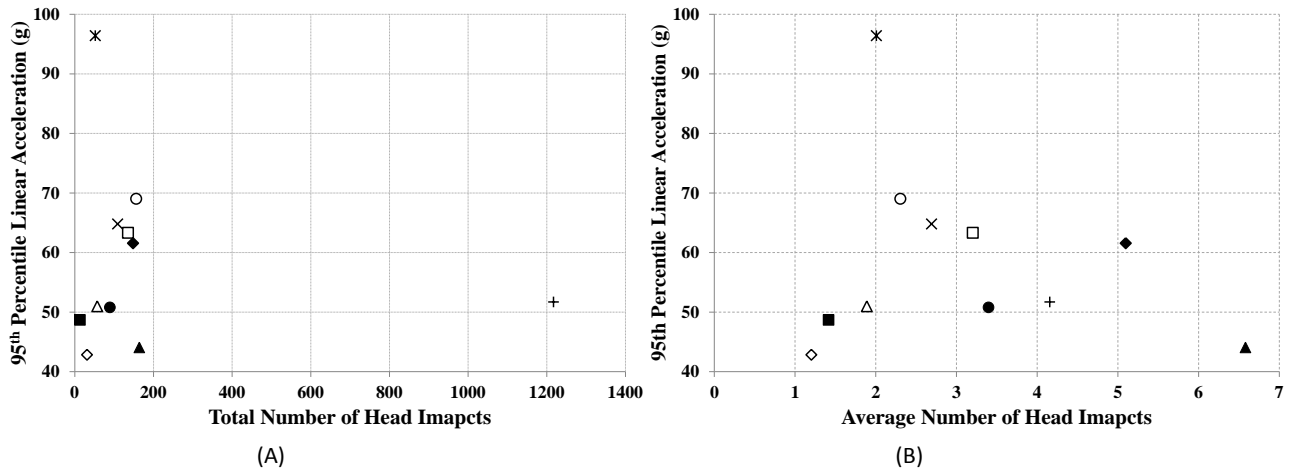


Figure 4: 95th percentile linear acceleration vs. (A) total number of head impacts in the season and (B) average number of impacts per player per drill session.

There were significant differences in mean linear ($p < 0.0001$) and rotational ($p = 0.003$) acceleration measured between drills (Figure 5). Open field tackling had significantly greater mean linear acceleration than install ($p < 0.0001$), kickoff practice ($p = 0.004$), multi-player tackle ($p = 0.0002$), passing drill ($p = 0.004$), position skill work ($p = 0.01$), and scrimmage ($p = 0.02$). One-on-one had significantly greater mean linear acceleration than install ($p = 0.003$) and multi-player tackle ($p = 0.02$). Additionally, open field tackling had significantly greater mean rotational acceleration than install ($p < 0.0001$), kickoff practice ($p = 0.0009$), multi-player tackle ($p = 0.01$),

Oklahoma ($p=0.02$), passing drill ($p=0.04$), position skill work ($p=0.002$), and scrimmage ($p=0.01$).

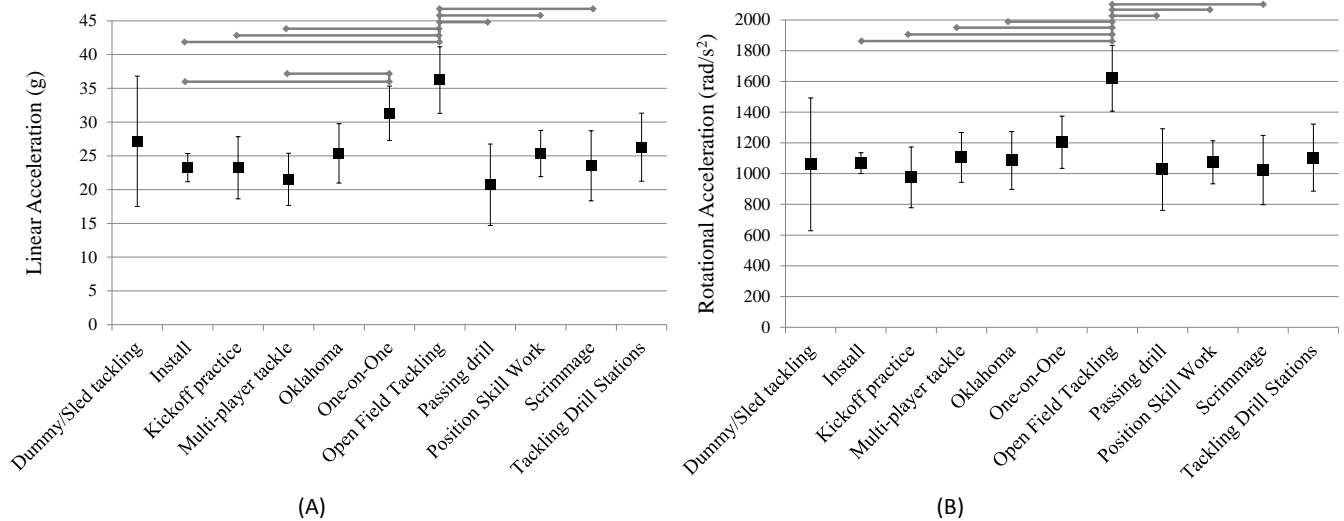


Figure 5: Mean and 95% confidence interval of (A) linear and (B) rotational acceleration for each drill. Lines connecting drills indicate significant differences in accelerations.

The mean number of impacts measured per athlete was evaluated for each drill session (Figure 6). The drill with the highest mean [95% confidence interval] number of impacts was multi-player tackle with 6.6 [4.4, 9.8] impacts, which was significantly greater than the mean number of impacts for dummy/sled tackling ($p=0.002$), kickoff practice ($p=0.0002$), one-on-one tackling ($p=0.04$), open field tackling ($p=0.001$), passing drill ($p<0.0001$), and position skill work ($p=0.0004$). Oklahoma had the second highest mean number of impacts with 5.1 [3.6, 7.2] impacts and had significantly greater number of impacts than dummy/sled tackling ($p=0.02$), kickoff practice ($p=0.003$), open field tackling ($p=0.02$), passing drill ($p<0.0001$), and position skill work ($p=0.01$). Install had significantly greater mean number of impacts than dummy/sled tackling ($p=0.02$), kickoff practice ($p<0.0001$), open field tackling ($p=0.004$), passing drill ($p<0.0001$), and position skill work ($p=0.001$). One-on-one and tackling drill stations had significantly greater mean number of impacts than passing drill ($p=0.02$ and $p=0.04$, respectively).

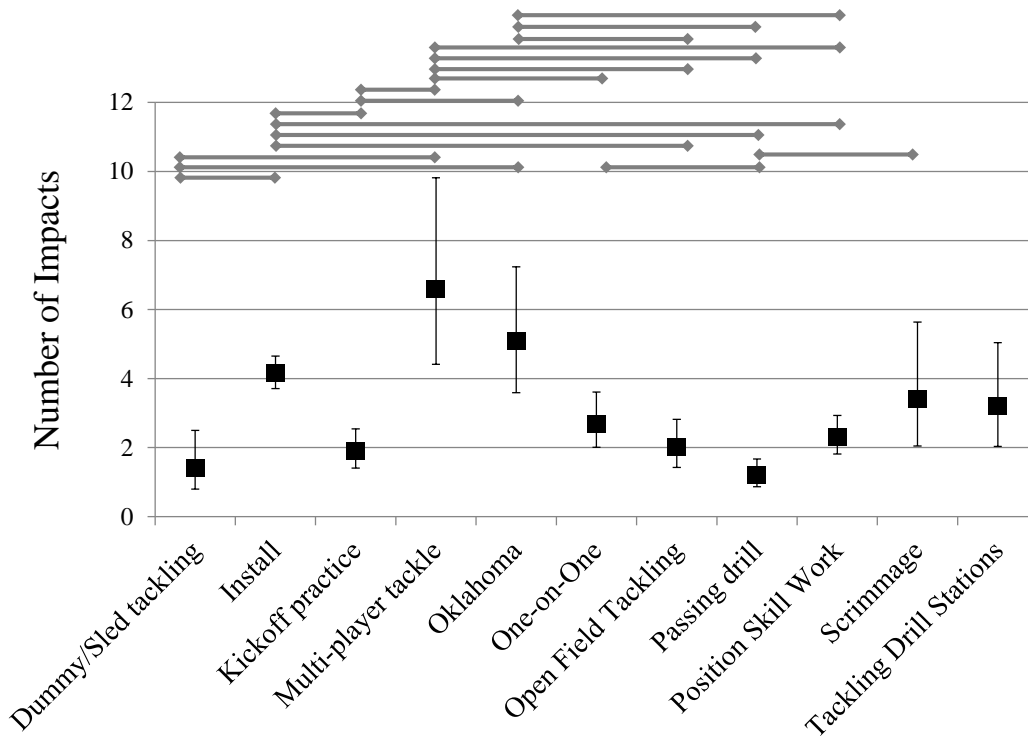


Figure 6: Number of impacts for each athlete for each drill in a practice session with 95% confidence interval. Lines connecting drills indicate significant differences in number of impacts. Refer to Table A1 for exact values.

Impacts to the front of the helmet were most common for all drills, except dummy/sled tackling (Figures 7 and 8). While only considering impacts equal to or greater than 60g, impacts to the top of the helmet were most common in the Oklahoma, one-on-one, open field tackling, and position skill work drills (50%, 86%, 44%, and 50% respectively). Impacts to the front of the helmet were most common for impacts measured over 60g during install, multi-player tackle, and tackling drill stations (45%, 100%, and 67%, respectively).

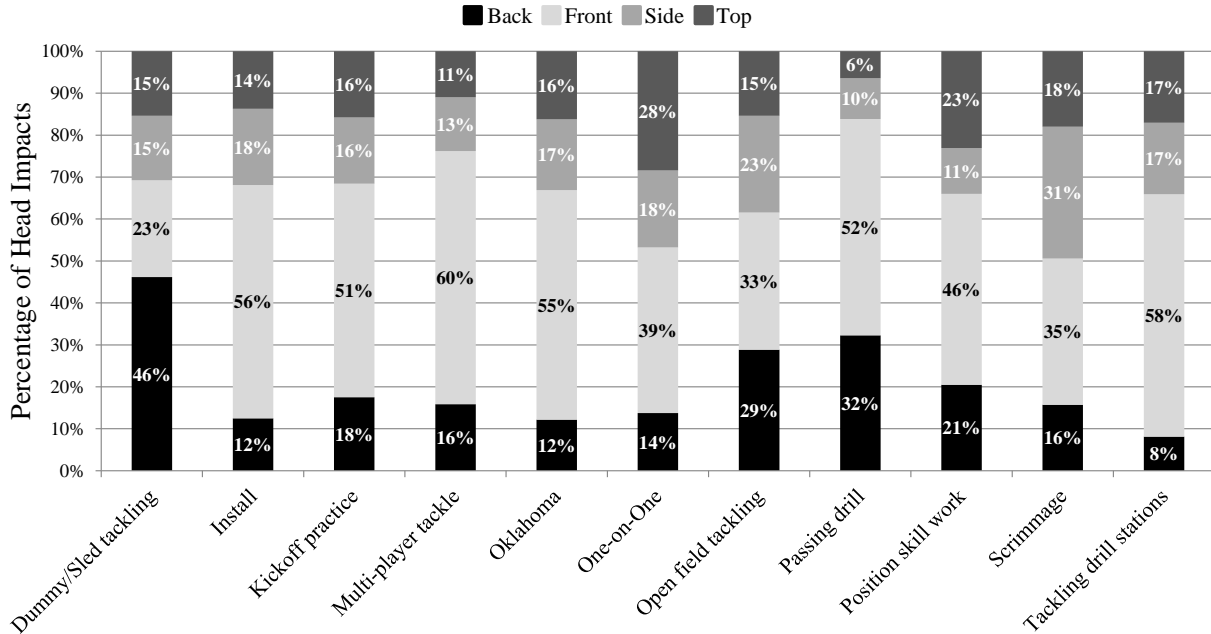


Figure 7: Percentage of head impacts by impact location for each drill. Refer to Table A1 for total number of impacts for each drill.

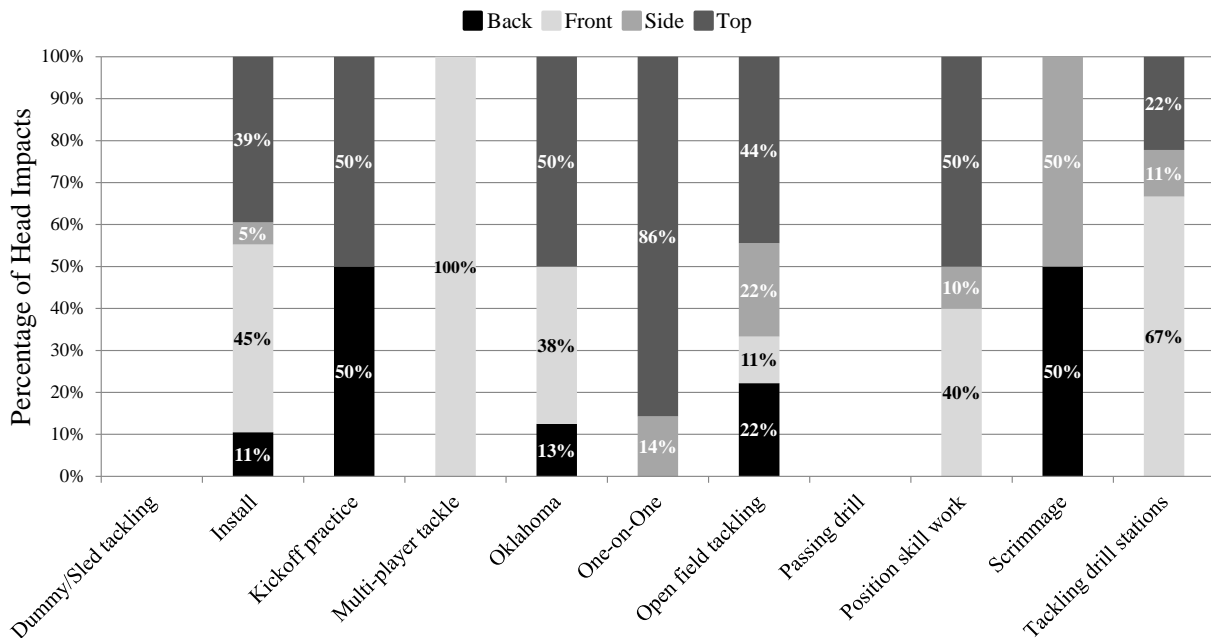


Figure 8: Percentage of head impacts greater than 60g by impact location for each drill. No impacts equal to or greater than 60g were measured during dummy/Sled tackling and passing drill. Refer to Table A1 for number of impacts above 60g for each drill.

DISCUSSION

By evaluating the head impact frequency and magnitude for all drills practiced by a youth football team, we demonstrated the variability in head impact exposure between drills. Open field tackling resulted in the highest median and 95th percentile linear and rotational accelerations (Table A1) with significantly greater mean head accelerations compared to several of the drills practiced by the team. Despite resulting in very high magnitude impacts, it was a relatively low frequency drill compared to other drills practiced by this team. This drill only occurred in 5 practices with an average of 2.0 [1.4, 2.8] impacts per player, so it made a relatively small contribution to the total number of impacts an athlete experienced in a practice and over the course of a season. As described in Table 1, the purpose of open field tackling drills is to improve tackling technique and positioning in game-like situations, but this drill may expose athletes to high magnitude head impacts, which are often greater than those experienced in games and may not be an accurate simulation of game-like scenarios. These results suggest that open field tackling drills may be modified such that the athletes start at a shorter distance apart, however considerations may be made to remove this drill entirely from youth football practice structures.

The one-on-one tackling drill was similar to open field tackling as both were player versus player tackling drills, but the one-on-one drill had the athletes start less than 3 yards from each other and there was a greater focus on improving form and technique rather than simulating game-like speed. One-on-one tackling had the second highest mean linear and rotational accelerations. Although it was still a high impact magnitude drill, the lower head impact magnitudes compared to open field tackling may be partially due to the athletes starting closer together and tackling at lower speeds. This drill had significantly higher mean number of impacts per athlete than passing drill, but only contributed 5% of all practice impacts. Therefore, similar to open field tackling, one-on-one was a lower frequency, but high magnitude drill.

Another tackling drill was the Oklahoma drill, but unlike open field and one-on-one tackling drills, Oklahoma was a high frequency drill with the second highest number of impacts per athlete (Table A1). The high frequency of impacts per athlete in a practice session is partially due to this drill involving four to six athletes in each play, rather than just two, so each athlete participates in more iterations of this drill during a practice. Another high frequency drill was multi-player tackle, which had a mean number of impacts per player of 6.6 [4.4, 9.8], the highest of all drills evaluated in this study. However, multi-player tackle had the second lowest 95th percentile linear acceleration of 44.1g, with only the passing drill having a lower 95th percentile linear acceleration. Additionally, this drill accounted for 7.6% of all practice impacts, only 3.4% of impacts greater than 60g, and 0% of impacts greater than 80g. Although multi-player tackle is still a tackling drill, it was more focused on blocking and encouraging the athletes to move their feet rather than tackling the opposing player to the ground. This shift in focus may be one of the reasons this drill generally had lower magnitudes of head impacts, but higher frequency when compared to other tackling drills.

The position skill work drill had the second highest 95th percentile linear acceleration, but because the team separated into offensive and defensive skill groups, it is suspected that the defensive skill group was contributing a greater proportion of high magnitude impacts compared to the offensive skill group. The defensive skill group often did one-on-one and sled tackling drills, while the offensive skill group would typically focus on passing-type drills. However, further analysis will be needed to understand if one skill group has greater head impact exposure

than the other. The dummy/sled tackling drill resulted in few recorded impacts. The reason is two-fold: this drill was only practiced 3 times during the season and head impacts were solely due to either contact with the dummy/sled or the ground. Dummy/sled tackling was generally a low impact magnitude and frequency drill, but more data are needed to better understand exposure during this drill.

Install was the most commonly practiced drill, resulting in 56% of all practice impacts. Install was done at almost every practice and resulted in an average of 4.2 [3.7, 4.7] impacts per player, the third highest number of impacts per player, following multi-player tackle and Oklahoma. Although the distribution of head impact magnitudes was not as high as other tackling drills like one-on-one, it was comparable to those observed in games (Table A1). Scrimmage was similar to the install drill in that both drills were full 11-on-11 practice with the purpose of practicing offensive and defensive strategy in a game-like scenario, however, scrimmage was between adjacent age and weight based teams, not just within the team participating in this study. Although the current team only did the scrimmage drill with each adjacent (above and below) age and weight level once, each on separate practice days, the distributions of linear and angular acceleration head impact magnitude were comparable to those in the within-team install drill (Figure 3). Nevertheless, more data are needed to determine if scrimmaging adjacent age and weight classified teams during practice has significantly different head impact exposure than within-team scrimmage. Variables such as amount of contact allowed by the coaches during between-team scrimmages and the differences in age and weight between the teams may affect head impact exposure and injury risk.

Lastly, head impact data were evaluated in terms of helmet impact location. The most common impact location for each drill, except dummy/sled tackling, was to the front of the helmet. However, the proportion of head impacts to the different impact locations changed when only evaluating impacts greater than 60g. For open field tackling, Oklahoma, one-on-one, and position skill work, impacts greater than 60g most commonly resulted in impacts to the top of the helmet, which could be indicative of improper tackling technique with athletes leading with their head instead of leading with their shoulder and keeping their head up. However, more in-depth video analysis of tackling technique and head impact surface (e.g. helmet, player, or ground) is needed to better understand how tackling technique can be improved to lower head impact exposure. Unlike other drills practiced by this team, dummy/sled tackling had the majority (46%) of head impacts occurring to the back of the helmet, which is partially due to the technique used during dummy tackling. The athletes would typically run up to the dummy, wrap their arms around it, and roll onto their backs after making the tackle.

The nine athletes in this study demonstrated variations in head impact exposure. Specifically, one athlete had 1003 head impacts and a 95th percentile linear acceleration of 63.7g, which were both the highest compared to all other athletes on the team. Some possible reasons for this athlete's increased head impact exposure include increased involvement and intensity in practices and games. Also, the majority of this athlete's impacts (53.1%) occurred in games rather than practices, differing from the relative proportions of game and practice impacts for the team as a whole. A sensitivity analysis removing individual athletes, including this athlete with higher head impact exposure, attenuates some of the significant relationships of head accelerations, however, the general trends and overall conclusions of the study remain unchanged.

A few limitations should be noted. First, this study only sampled nine athletes from one youth football team. This sample size is small compared to some other studies at the high school

and collegiate level (Urban, Davenport et al. 2013; Liao, Lynall et al. 2016). Second, the results are a limited snapshot of the youth population, as youth football leagues include athletes from 5-15 years old. However, this study of head impact exposure in youth football practice drills is ongoing and future work will be conducted to evaluate head impact exposure in practice drills for multiple seasons and between age and weight based teams at the youth level. Third, factors such as league-specific or organization-specific regulations for practices and games may influence head impact exposure. This work is part of a multi-site study and will be expanded upon to include several youth leagues within various national organizations and demographic/cultural backgrounds. Fourth, the HIT system has some measurement error, but the error in 5DOF acceleration measurements are within the range of acceptable error for other measurement devices and methods (Beckwith, Greenwald et al. 2012).

CONCLUSIONS

This study quantified head impact exposure in youth football practice drills for a single youth football team and found that head impact exposure varies significantly between drills. Further research is needed to fully understand the role of coach/athlete interaction, corrective behavior, and proper tackling technique on head impact exposure. Evaluating head impact exposure in youth football practice drills is an important step in informing coaches, leagues, and organizations on methods to restructure practice and implement rules and regulations to reduce head impact exposure and make sports safer for youth.

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APPENDIX

Table A1: Summary of impact frequency and impact magnitude for each practice drill. Average number of impacts per player is computed per practice session

Rotational Acceleration (rad/s ²)		Linear Acceleration (g)		Average Number of Impacts Per Player [95% Confidence Interval]	Number of Sessions	N (Impacts >80g)	N (Impacts > 60)	N (Total)	Drill
95th Percentile	50th Percentile	95th Percentile	50th Percentile						
1576.34	905.51	48.7	18	1.41 [0.80, 2.50]	3	0	0	13	Dummy/Sled tackling
2270.22	953.16	51.7	19.7	4.16 [3.71, 4.65]	33	12	38	1217	Install
2063.35	833.11	50.98	18.7	1.89 [1.40, 2.54]	10	0	2	57	Kickoff practice
2279.67	1018.4	44.08	21.4	6.58 [4.41, 9.82]	3	0	3	164	Multi-player tackle
2957.98	1074.28	61.57	22.85	5.10 [3.59, 7.24]	5	3	8	148	Oklahoma
2578.56	894.62	64.8	22.6	2.69 [2.01, 3.61]	7	3	7	109	One-on-One
3809.24	1326.38	96.41	24.65	2.01 [1.43, 2.82]	5	5	9	52	Open Field Tackling
2342.76	950.3	42.84	17	1.20 [0.87, 1.67]	17	0	0	31	Passing drill
2554.24	902.56	69.04	19.5	2.31 [1.81, 2.93]	12	4	10	156	Position Skill Work
2197.59	869.78	50.8	18.9	3.40 [2.05, 5.64]	2	1	2	89	Scrimmage
2524.49	1010.19	63.32	21.2	3.20 [2.03, 5.04]	4	1	9	135	Tackling Drill Stations
2335.9	960.1	56.1	20.1	6.19 [5.47, 7.00]	36	29	88	2171	All Practices
2430.5	986.8	54	20.9	12.37 [10.08, 15.18]	11	18	60	1590	All Games