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Differences in Head Impact Exposures Between Youth Tackle and Flag Football Games and Practices:

Potential Implications for Prevention Strategies

Kelly Sarmiento, MPH[*],[†], Dana Waltzman, PhD[†], Owen Devine, PhD[‡], Xinjian Zhang, PhD[†], Lara DePadilla, PhD[§], Marcie-Jo Kresnow, MS[†], Kelley Borradaile, PhD[‖], Andrew Hurwitz, PhD[‖], David Jones, PhD[‖], Ravi Goyal, PhD[‖], Matthew J. Breiding, PhD[†]

[†]Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, Division of Injury Prevention, Atlanta, Georgia, USA.

[‡]Premier Federal Inc, Atlanta, Georgia, USA.

[§]Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, Division of Overdose Prevention, Atlanta, Georgia, USA.

[‖]Mathematica Policy Inc, Princeton, New Jersey, USA.

Abstract

Background: Interventions designed to reduce the risk for head impacts and concussion in youth football have increased over the past decade; however, understanding of the role of regular game play on head impact exposure among youth tackle and flag football athletes is currently limited.

Purpose: To explore head impact exposure among youth tackle and flag football athletes (age range, 6–14 years) during both practices and games.

Study Design: Cohort study; Level of evidence, 2.

Methods: Using the Vector MouthGuard sensor, the authors collected head impact data from 524 tackle and flag youth football athletes over the course of a football season. Quantities of interest were estimated from regression models using Bayesian methods.

Results: For impacts ≥10*g*, a tackle football athlete had an estimated 17.55 (95% CI, 10.78–28.96) times more head impacts per practice compared with a flag football athlete (6.85 [95% CI, 6.05–7.76] and 0.39 [95% CI, 0.24–0.62] head impacts, respectively). Additionally, a tackle football athlete had an estimated 19.48 (95% CI, 12.74–29.98) times more head impacts per game compared with a flag football athlete (13.59 [95% CI, 11.97–15.41] and 0.70 [95% CI, 0.46–1.05] head impacts, respectively). Among tackle football athletes, the estimated average impact rate was 6.51 (95% CI, 5.75–7.37) head impacts during a practice and 12.97 (95% CI, 11.36–14.73) impacts during a game, resulting in 2.00 (95% CI, 1.74–2.29) times more ≥10*g* head impacts in

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[*]Address correspondence to Kelly Sarmiento, MPH, Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, Division of Injury Prevention, 4770 Buford Hwy, NE, MS S106-09, Atlanta, GA 30341, USA (ksarmiento@cdc.gov).

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games versus practices. Tackle football athletes had 2.06 (95% CI, 1.80–2.34) times more high-magnitude head impacts ($\geq 40g$) during a game than during a practice. On average, flag football athletes experienced an estimated 0.37 (95% CI, 0.20–0.60) head impacts during a practice and 0.77 (95% CI, 0.53–1.06) impacts during a game, resulting in 2.06 (95% CI, 1.29–3.58) times more $\geq 10g$ head impacts in games versus practices. Because of model instability caused by a large number of zero impacts for flag football athletes, a comparison of high-magnitude head impacts is not reported for practices or games.

Conclusion: This study provides a characterization of the head impact exposure of practices and games among a large population of youth tackle and flag football athletes aged 6 to 14 years. These findings suggest that a greater focus on game-based interventions, such as fair play interventions and strict officiating, may be beneficial to reduce head impact exposures for youth football athletes.

Keywords

head impact; practice; game; football; concussion; sensor

There were more than a quarter million emergency department visits made by children and adolescents for a sports-or recreation-related traumatic brain injury (TBI), including concussion, between 2010 and 2016.[39] Because of the likelihood of intentional (eg, tackling) and unintentional collisions (either between athletes or from a fall to the ground) in football, this sport was associated with more than a quarter (26.8%) of these emergency department visits.[30,39]

A concussion is a type of mild TBI. Caused by a bump, blow, or jolt to the head,[9,32] a concussion results in chemical changes in the brain.[21] These changes may lead to short- or long-term clinical signs and symptoms[21] that may evolve over the course of recovery.[41] Signs and symptoms of concussion often fall into 4 categories: somatic symptoms (eg, headache, nausea), changes in behavior and emotional functioning (eg, irritability, sadness), cognitive symptoms (eg, difficulty concentrating or slowed reaction time), and sleep problems (eg, sleeping more than usual, trouble falling asleep).[10]

While research is ongoing regarding potential long-term effects and acceptable levels (number and magnitude) of head impacts for youth athletes, reducing the overall number of head impacts is a critical component of concussion prevention strategies in youth football and other sports.[22] As such, there is substantial interest in research that focuses on the incidence of head impact exposures, as well as the activities that increase the risk for head impact exposures among youth football athletes. Using data from helmet sensors, past studies have demonstrated that as youth football athletes increase in age, there is a corresponding increase in the number of impacts and the magnitude of linear acceleration per athlete over the course of a football season.[5,6,13,17,34] Moreover, depending on an athlete's position on a tackle football team, the number of head impacts that a high school athlete may sustain can vary from as few as 5 to as many as 2235 impacts per season.[5]

Flag football is a form of American football in which tackling is prohibited. Instead, an athlete removes a flag or flag belt from a ball carrier to end a play. The promotion of flag football as an alternative to tackle football for youth athletes, as well as interventions designed to reduce the risk for head impacts and concussion in tackle football, has increased over the past decade.[15,22] Tackle football safety interventions primarily focus on modifying tackling techniques, restricting the amount of preseason practices, and restricting the amount of time during practices in which athletes are allowed to engage in tackling and other athlete-to-athlete contact.[1,22,44] While some evidence has suggested that rule changes, such as changing the location of the kickoff line, reduce the risk for concussion among college-aged athletes, the effect of rule changes and the role of regular game play on head impact exposure among youth football athletes (under high school age) are less clear.[48] Moreover, to our knowledge, only 1 study has assessed differences in head impact exposures during games and practices among youth flag football athletes.[29] As there are observed differences between practice and games in athlete and coach behavior, such as reduced concussion reporting by athletes and greater use of aggressive actions during games,[11,12,45] further investigation is warranted.[22]

The goal of this study was to expand upon what is currently known about head impact exposure among youth tackle and flag football athletes during both practices and games. These findings may help to inform the development of future strategies that mitigate the risk for head impacts in youth football, which may be used by coaches and on-field health care professionals, as well as schools and football programs.

METHODS

Participants

Head impact data were collected from 42 youth football teams (36 youth tackle football and 6 flag football teams) in New York. Both football leagues had 4 age-based divisions. The teams were selected for the study using a systematic random-sampling approach with teams stratified by division and league; up to 16 athletes per team were selected for inclusion. The results presented are based on impact data from 524 athletes (477 tackle and 47 flag football athletes). Impact counts for 5 athletes were judged to be outliers. The data for those athletes were removed from the analyses (see the Appendix, available in the online version of this article). Data were collected over the course of the tackle (fall 2017) and flag (spring 2018) football seasons. Youth tackle football athletes were aged 6 to 14 years, and flag football athletes were aged 7 to 14 years. For the tackle football teams, a randomized controlled trial that examined the differences between 2 tackling techniques and the use of robotic dummies was implemented. However, there were no statistically significant differences in the number of head impacts or median linear acceleration between the conditions. Thus, the data obtained for all tackle football athletes were combined. Additional details on the study population and the head impact exposure rates for youth tackle football athletes as compared with youth flag football athletes over the course of the youth football season have been described elsewhere.[46] Institutional review board approval was obtained from the New England Independent Review Board. The research team obtained informed consent from participating athletes’ parents and assent from the athletes.

Mouth Guards

Youth football athletes were equipped with the Vector MouthGuard (Athlete Intelligence) (Figure 1). The mouth guard measured magnitude of head acceleration and was optimized for impacts between 10*g* and 200*g* (*g* is a measurement of gravitational force equivalent). As flag football athletes do not wear helmets, mouth guards allowed for the assessment of head impacts using a consistent method. The mouth guard was fitted for each athlete's bite through a standard boil-and-bite process for a secure custom fit. The Vector MouthGuard uses a triaxial accelerometer to measure linear acceleration and a triaxial angular rate gyroscope to measure rotational kinematics.[7] Data acquisition is triggered when the sensor measures 3 consecutive samples >10*g* in any axis. When triggered, the instrumentation stores 16 milliseconds of pretrigger and 80 milliseconds of posttrigger data on the mouth guard's memory chip. Coaches or their designee uploaded the data using a sideline receiver and base station (product No. 350–00003; Athlete Intelligence). To determine impact (total, 186,239 events) versus nonimpact events (total, 1,405,808 events), events were classified 2 ways. First, to reduce the likelihood of false-positive impacts, a capacitive in-mouth sensor determined when the mouth guard was present in the mouth; impacts that occurred outside an athlete's mouth were removed. Second, a support vector machine classifier (product No. 350–00003; Athlete Intelligence) was used to reject nonimpact events, such as chewing, clenching, and drinking. From previous studies, the sensor has been shown to have high validity compared with an anthropomorphic test device and is consistent with what has been seen in another mouth guard sensor and helmet sensors.[3,7,23,24,36] For example, peak linear acceleration measurements across all 128 impact sites were highly correlated between the mouth guard sensor and an anthropomorphic test device ($r^2 = 0.96$) and demonstrated a 9.9% ± 4.4% average normalized root-mean-square error (± SD) for impact time traces for linear acceleration. For more in-depth information about the sensor and sensor validation, refer to the studies of Camarillo et al[7] and Snyder and Haensly.[43] Impacts were not verified using video.

Data Analysis

The analytic sample was limited to head impacts collected during the regular football season because of differences in pre- and postseason activities between flag and tackle football programs. The analysis excluded data from impacts (n = 3857, accounting for 2% of the data) with an inconsistent time stamp (eg, a head impact occurred before or after a practice or game) due to sensor error. The statistical package OpenBugs Version 3.2.3 (www.openbugs.net) was used for analysis. Descriptive measures of variability (median ± interquartile range) were calculated for head impact metrics.[49] Head impact exposure was quantified in terms of number of head impacts (≥10*g*) and high-magnitude impacts (≥40*g*). In addition, the 50th and 95th percentiles of linear acceleration impacts for each athlete were calculated and then averaged across athletes.

Because of a large number of zero-impact counts (eg, athletes with no recorded impacts ≥10*g* for an individual game or practice), impact rates were developed using a zero-inflated Poisson (ZIP) model (see the Appendix, available online).[20] To account for overdispersion in impact counts, athlete-level random effects were also included in the model. For comparison of impact rates between games and practices within football type, the ZIP modeling approach was modified to account for the repeated measurements inherent in these analyses (each athlete contributed 2 outcomes: 1 for games and 1 for practices). This was done by assigning each athlete 2 correlated random effects, which were assumed to be random variables sampled from a multivariate normal distribution. The actual number of games and practices in which tackle football athletes participated was not available for these analyses. As a result, each tackle football athlete was assumed to have attended the sum of the number of events, games, or practices in which any member of his team had at least 1 recorded impact. Because of a large number of zero total impact counts among flag football athletes, impact rates of magnitude were not estimated at ≥40*g* for flag football athletes.

Estimates of 50th and 95th percentile linear acceleration were developed under the assumption that these values followed a Student *t* distribution. This approach was used to derive estimates of average acceleration that are more robust to the fact that many players had large values for these outcomes.[49] Linear acceleration models included athlete-level random effect for the comparisons of games and practices within football type to account for the fact that athletes may contribute >1 outcome to these analyses. Moreover, estimates may differ slightly when the data are stratified by type of football played (ie, tackle, flag) and games versus practices. For example, the estimated average head impact rates using combined data from tackle and flag football athletes differ slightly from the estimates when the data are restricted to solely tackle or solely flag football athletes.

Bayesian methods were used to estimate the parameters of all models. A Bayesian approach was selected for all models (final model and sensitivity analyses) for a variety of reasons including flexibility of modeling, interpreting random effects,[19] the ability to estimate the uncertainty of functions of the model parameters, and consistency with methods used to impute values for the missing game or practice counts for tackle football athletes. All models for the number of impacts and linear acceleration were compared with alternatives that included potential age effects, both categorical and linear, for the outcomes. Because individual age was not available in these data, each athlete was assigned an age based on the midpoint age for the division in which he participated. Details on the underlying assumptions used to develop the models, the imputation method for missing tackle exposure counts, and additional sensitivity analyses evaluating the impact of modeling assumptions on the estimates of interest are presented in the Appendix (available online).

RESULTS

Figure 2 depicts the frequency of head impacts during the regular season (fall 2017 for tackle football and spring 2018 for flag football).

Head Impact Exposure During Practices: Comparison of Youth Tackle and Flag Football Athletes

Per practice, there were 6.85 (95% CI, 6.05–7.76) head impacts estimated for a tackle football athlete and 0.39 (95% CI, 0.24–0.62) head impacts for a flag football athlete (Table 1); a tackle football athlete had an estimated 17.55 (95% CI, 10.78–28.96) times more head impacts per practice compared with a flag football athlete. The linear acceleration 50th percentile impacts for each athlete were similar between tackle and flag football athletes.

However, the 95th percentile of linear acceleration per athlete, averaged across athletes, was an estimated 50.39*g* (95% CI, 48.74–52.04*g*) for a tackle football athlete and 23.85*g* (95% CI, 19.19–28.98*g*) for a flag football athlete, which was 26.54*g* (95% CI, 21.24–31.40*g*) higher among tackle versus flag football athletes. A comparison of high-magnitude head impacts is not reported due to model instability caused by a large number of zero-impact practices for flag football athletes.

Head Impact Exposure During Games: Comparison of Youth Tackle and Flag Football Athletes

On average, per game, there were an estimated 13.59 (95% CI, 11.97–15.41) head impacts for a tackle football athlete and 0.70 (95% CI, 0.46–1.05) head impacts for a flag football athlete (Table 1). Additionally, a tackle football athlete had an estimated 19.48 (95% CI, 12.74–29.98) times more head impacts per game compared with a flag football athlete. The linear acceleration 50th percentile impacts for each athlete were similar between tackle and flag football athletes. The 95th percentile of linear acceleration per athlete, averaged across athletes, was an estimated 50.67*g* (95% CI, 48.97–52.41*g*) for a tackle football athlete and 32.74*g* (95% CI, 27.17–38.53*g*) for a flag football athlete, which was 17.94*g* (95% CI, 11.93–23.70*g*) higher among tackle versus flag football athletes. High-magnitude head impacts are not reported because of model instability due to a large number of zero-impact games for flag football athletes.

Assessment of Head Impact Exposure During Games and Practices Among Youth Tackle Football Athletes

On average, per tackle football athlete, there were an estimated 12.97 (95% CI, 11.36–14.73) head impacts during a game and 6.51 (95% CI, 5.75–7.37) head impacts during a practice (Table 2); a tackle football athlete had 2.00 (95% CI, 1.74–2.29) times more head impacts per game compared with a practice. The linear acceleration 50th and 95th percentile impacts for a tackle football athlete were similar between practices and games. Examining high-magnitude head impacts (≥40*g*), a tackle football athlete was estimated to sustain 1.43 (95% CI, 1.24–1.64) head impacts during a game and 0.70 (95% CI, 0.61–0.79) head impacts during a practice, which translates to 2.06 (95% CI, 1.80–2.34) times more ≥40*g* head impacts per game compared with a practice.

Assessment of Head Impact Exposure During Games and Practices Among Youth Flag Football Athletes

On average, per flag football athlete, there were an estimated 0.77 (95% CI, 0.53–1.06) head impacts during a game and 0.37 (95% CI, 0.20–0.60) head impacts during a practice (Table 2); a flag football athlete had 2.06 (95% CI, 1.29–3.58) times more head impacts per game compared with a practice.

The linear acceleration 50th percentile impact for a flag football athlete was similar between practices and games. The average 95th percentile of linear acceleration per flag football athlete was estimated to be 32.46g (95% CI, 26.61–38.50*g*) during a game and 23.69g (95% CI, 18.84–29.19*g*) during a practice, which translates to 8.69g (95% CI, 1.51–15.83*g*) higher impact for games as compared with practices for a flag football athlete. High-magnitude head impacts are not reported because of model instability due to a large number of zero-impact practices, games, or both for flag football athletes.

DISCUSSION

This study characterizes the head impact exposure at practices and games among a large population of youth tackle and flag football athletes aged 6 to 14 years. In this study, both tackle and flag football athletes had 2 times more head impacts during a game than during a practice. Tackle football athletes sustained a greater rate of head impacts per practice and per game compared with flag football athletes. Tackle football athletes also had more high-magnitude impacts ($\geq 40g$ head impacts) during a game than during a practice. These findings suggest that a greater focus on game-based interventions to reduce head impact exposures may be beneficial.

As the majority of head impacts and concussions in youth football are caused by collisions and athlete-to-athlete contact, the marked differences in the per-practice and per-game head impact exposure risk between tackle and flag football athletes in this study are not surprising.[30] Still, the substantial risk for head impact exposures for both youth tackle and flag football athletes in games as compared with practices does point to potential gaps in current prevention strategies. A possible explanation for the disparity in rates between games and practices may include differences in play, such as the increased likelihood of illegal actions (ie, fouls and penalties) and more aggressive behaviors during games.[33] Collins and colleagues[14] found that approximately a quarter of the concussions among high school athletes were associated with illegal play activity as determined by a referee or disciplinary committee. Strict officiating by sports officials during games and adherence to rules by coaches and athletes have been shown to decrease rates of head impact exposures and concussions, as well as to reduce aggressive actions that increase the risk for injury in football and other sports.[2,16,22] As such, the 2017 consensus statement on concussion in sport called for a focus on fair play and sportsmanship and highlighted the critical role that coaches and parents play in the implementation of such efforts.[31] Currently, to our knowledge, there is no research examining ways to increase fair play and sportsmanship strategies and their effect on head impact and concussion risk in youth football. However, some examples of fair play interventions that have led to reductions in injury risk in other sports (eg, soccer and ice hockey) include the use of fair play rules and increasing penalty infraction minutes in ice hockey.[22,26]

Games are an opportunity for youth tackle football athletes to work as a team and test their skills, but games also present an increased risk for high-magnitude head impacts. High-magnitude impacts are associated with a greater risk for concussion[37,44] and with changes to brain integrity.[42] In this study, a tackle football athlete had almost 20 times more head impacts per game compared with a flag football athlete. While there are promising findings regarding reductions in head impact exposure rates for youth tackle football athletes during practices, practice-based contact limitations have not been found to effectively reduce head impact exposures or concussions during games.[6,22,25,35] As opposed to contact limitations, which limit the amount of contact practices or drills, some ice hockey programs have banned high-risk contact for the youngest athletes during both games and practices. Emery and colleagues[18] assessed the effect of restricting contact on injury rates through an examination of 2 ice hockey leagues: 1 that instituted a ban on body checking for youth ice hockey athletes and 1 that did not. They found no difference in practice-related injury rates between the 2 leagues. However, they did find a 3-fold decrease in the risk of concussion and injury during games among the non–body checking leagues as compared with body-checking leagues. Taken together, these findings highlight the potential benefits of expanding the use of noncontact or flag football programs for youth football athletes.

Head impact exposure and concussion risk vary by an athlete's playing position and the type of play (eg, throwing play, punt, or kickoff returns).[5,6,40] Playing positions that increase an athlete's risk for sustaining a head impact or concussion may include linemen, linebackers, and running backs.[5,30] Moreover, a disproportionate number of concussions in tackle football happen after long closing distances, such as during running plays and kickoff and punt returns.[40] Broglio and colleagues[6] examined head impact exposure among high school football athletes and found that after implementation of practice-based contact limitations (eg, no more than 2 collision practice days in any week), head impacts for the football season decreased by 37% among linemen and 25% among tight ends, running backs (including fullbacks), and linebackers. Similarly, because of concerns of high-speed collisions that may occur when a receiver runs the ball back from a punt or kickoff, some collegiate football programs instituted rule changes intended to limit the likelihood of this type of play.[48] An analysis of the concussion rate before and after these rule changes found 7.51 fewer concussions for every 1000 kickoff plays after the rule change.[48] Several youth football programs have instituted similar rule changes regarding punts and kickoffs, including the football program that participated in this study. To our knowledge, there are currently no studies that have examined the effect of this rule change on head impact exposure or concussion risk at the youth level (under high school age) or how playing position or the type of play affects injury risk among flag football athletes. As such, future assessment of these factors in flag football, as well as the effect of rule changes to address high-risk plays and playing positions, may be beneficial.

Findings from this study are consistent with those of several previous head impact exposure studies[4,8,13,17,28,50] examining youth tackle football athletes that have demonstrated greater head impact exposure during games compared with practices. For example, our results revealed that tackle football athletes had 2 times more $\geq 10g$ head impacts per game than practice, which is also similar to that reported in previous studies.[17,28,50] Still, rates of head impact exposure among studies may vary, and at least 1 study of youth tackle football athletes found no difference in head impact exposures between games and practices.[4,51] Additionally, the only other study exploring head impact exposure rates during games and practices among flag youth athletes found opposite results to this study, with higher head impact exposure rates in practices.[29] Differences in findings between this and other studies may be attributed to a variety of factors, such as the use of different sensor modalities (sensors placed in helmets, mouth guards, skin patches, etc), different metrics for analysis (frequency vs rate), differing sample sizes and ages of study participants, inconsistent definitions of high-magnitude impacts ($\geq 40g$, $\geq 60g$, or $\geq 80g$ or using the 95th percentile of linear acceleration), and football program–specific rules (eg, age-based restrictions).

Finally, participation in organized youth football programs has declined by almost a quarter over the past decade,[1] likely a key driver for a similar decline in emergency department visits for sports- and recreation-related TBIs during the same period.[47] Concerns among parents may be one explanation for decreased participation in youth tackle football. Conversely, there has been an increase in flag football participation in recent years,[1] which may indicate a growing preference among parents, as well as some schools and sports programs, for noncontact football. However, research has suggested that access to community-based flag football programs is not equitably distributed.[27] Kroshus and colleagues[27] found that people living in communities with fewer college-educated residents were less likely to have access to flag football programs. This finding may contribute to health inequities[27] and is consistent with those of other studies that have demonstrated an association between less access to organized youth sports activities in communities and lower socioeconomic status.[38]

This study is subject to several limitations. First, because of the observational nature of the data, the results may not be generalizable to a larger population of tackle and flag football athletes. Second, there are likely differences in athlete characteristics between those who choose to play tackle versus flag football, which may have affected the results. We attempted to address athlete-level differences for impact risk beyond those associated with the type of football by adding athlete-level random effects in the model. Third, head impacts were not verified using video. This may have resulted in the inclusion of some invalid head impact exposures. Lack of video was consistent throughout both the tackle and flag football seasons and likely affected them similarly. Fourth, the study did not collect attendance data (exposure) for the tackle football teams. To address this, we assumed a tackle football athlete was present at each session in which any athlete on the team had a recorded impact. This assumption likely results in an underestimate of the rate of impacts at games and practices for tackle football and represents a conservative estimate comparing the relative risk of impacts with flag football athletes. In addition, we conducted sensitivity analyses in which these missing data were imputed as part of the Bayesian estimation process, which demonstrated a higher rate ratio of impacts for tackle compared with flag football for both games and practices due to a larger estimate in impact rates among tackle football athletes (see the Appendix, available online). Fifth, there was a much smaller number of flag football athletes compared with tackle football athletes (47 vs 477) in our study. However, to our knowledge, this is the largest number of flag football athletes that has had head impact exposure examined thus far. Continued research with larger sample sizes of flag football athletes would aid in understanding this group. Sixth, because of the large number of flag football athletes who did not sustain a ≥40*g* impact, as well as the lower number of flag football athletes, we only reported high-magnitude impact (≥40*g*) results for tackle football athletes. This led to model instability in the flag football athletes, and thus some results were not able to be calculated. Additionally, this limited our ability to assess even higher impacts (≥60*g* or ≥80*g*). Seventh, individual athlete characteristics, such as age, playing position, height, and weight, were not available. Thus, we were not able to assess the effects of the factors of head impact exposure risk. The analyses that examined age (see the Appendix, available online) were based on a midpoint age of each division. Eighth, because of a lack of standardization in the literature regarding analysis of rotational acceleration, this information was not included. Ninth, an uneven distribution of playing time among athletes and variations in the number and length of games and practices (both between tackle and flag and between games and practices within each type of play) may also explain some of the variation in head impact exposure risk. These factors were not available for inclusion in comparisons between flag and tackle football. Tenth, concussion risk was not assessed as a part of this study. Further investigation, especially at the youth level, is warranted.

CONCLUSION

This paper presents findings from one of the first studies to assess head impact exposure in games and practices among youth flag football athletes. In this study, both tackle and flag football athletes had approximately 2 times more head impacts during a game than during a practice. Games were also associated with an increased risk for high-magnitude head impacts for tackle football athletes, who sustained almost 20 times more head impacts per game compared with flag football athletes. These findings suggest that a greater focus on game-based interventions, such as fair play interventions and strict officiating, may be beneficial to reduce head impact exposures for youth football athletes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Vector MouthGuard manufactured by Athlete Intelligence.

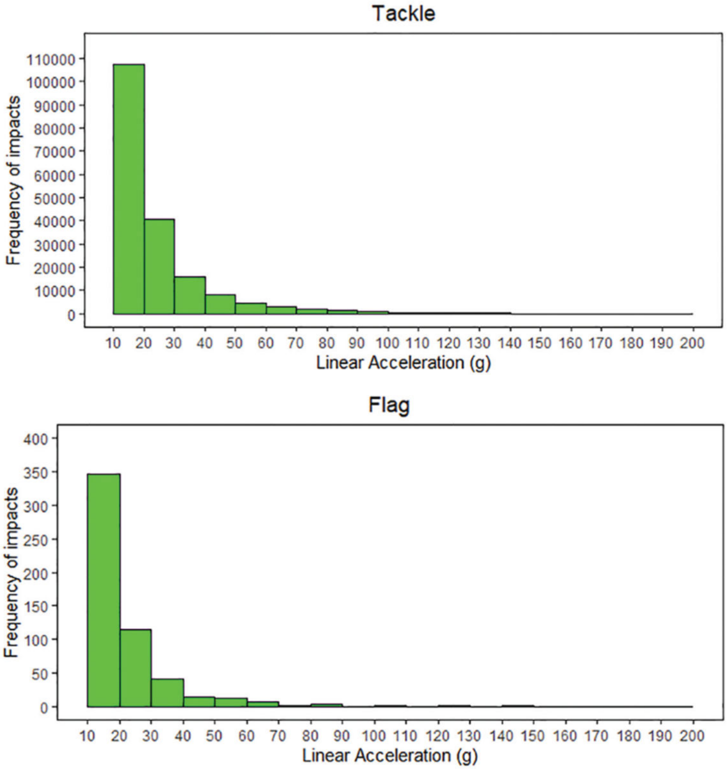

Figure 2.

Histogram of head impacts during the regular tackle and flag football seasons.

TABLE 1

Model Estimates and Comparisons of Head Impact Exposure at Games and Practices Between Youth Tackle and Flag Football Athletes (n = 477)[a]

Outcome	Estimates[b]	Season	Practice	Game
No. of impacts	Average rate of impact per athletic exposure[c]			
	Tackle	9.19 (8.18 to 10.32)	6.85 (6.05 to 7.76)	13.59 (11.97 to 15.41)
	Flag	0.63 (0.43 to 0.92)	0.39 (0.24 to 0.62)	0.70 (0.46 to 1.05)
	Rate ratio			
	Tackle to flag	14.67 (9.75 to 21.95)	17.55 (10.78 to 28.96)	19.48 (12.74 to 29.98)
	Probability ≥1 impact			
	Tackle	1 (1 to 1)[e]	0.95 (0.93 to 0.97)	0.90 (0.87 to 0.92)
	Flag	0.47 (0.35 to 0.60)	0.32 (0.21 to 0.46)	0.49 (0.36 to 0.62)
Linear acceleration (50%)	Average 50th percentile			
	Tackle	18.15 (17.95 to 18.34)	17.86 (17.66 to 18.07)	18.35 (18.13 to 18.57)
	Flag	16.84 (15.57 to 18.21)	16.00 (14.92 to 17.15)	16.93 (15.46 to 18.59)
	Increase in 50th percentile[d]			
	Tackle vs flag	1.31 (–0.08 to 2.59)	1.86 (0.69 to 2.96)	1.42 (–0.24 to 2.90)
	Degrees of freedom	3 (2 to 4)	2 (2 to 3)	4 (3 to 5)
	Probability 50th percentile greater during games			
	Tackle ≥ flag	0.97	1	0.95
Linear acceleration (95%)	Average 95th percentile			
	Tackle	52.55 (51.06 to 54.09)	50.39 (48.74 to 52.04)	50.67 (48.97 to 52.41)
	Flag	33.51 (28.23 to 39.08)	23.85 (19.19 to 28.98)	32.74 (27.17 to 38.53)
	Increase in 95th percentile			
	Tackle vs flag	19.06 (13.38 to 24.45)	26.54 (21.24 to 31.40)	17.94 (11.93 to 23.70)
	Degrees of freedom	6 (4 to 12)	6 (4 to 9)	7 (4 to 15)
	Probability 95th percentile greater during games			
	Tackle ≥ flag	1 (1 to 1)[e]	1 (1 to 1)[e]	1 (1 to 1)[e]
High-magnitude impacts (≥40*g*)	Average rate of impact per athletic exposure			
	Tackle	1.01 (0.90 to 1.13)	—	—
	Flag	0.04 (0.03 to 0.07)	—	—

Outcome	Estimates[b]	Season	Practice	Game
	Rate ratio			
	Tackle to flag	23.00 (13.59 to 39.55)	—	—
	Probability ≥1 impact			
	Tackle	0.63 (0.58 to 0.67)	—	—
	Flag	0.04 (0.03 to 0.07)	—	—

[a] Estimates and comparisons were for those aged 6 to 14 years, by outcome variable (number of impacts, 50th percentile of linear acceleration, 95% percentile of linear acceleration, and high-magnitude impacts [≥40*g*]), in New York, 2017 and 2018. Data in parentheses are 95% CI. Dashes indicate that models were not stable and results were not calculated.

[b] Estimates may differ slightly when the data are stratified by type of football played (ie, tackle, flag) and games versus practices.

[c] Athletic exposure is defined as a youth football practice or game.

[d] Reported value is the proportion of posterior samples in which estimate for games exceeded that for practice. Therefore, no CI is reported.

[e] Lower bound of 95% CI is estimated to be equal to 1 when rounded to 2 significant digits.

TABLE 2

Model Estimates and Comparisons of Head Impact Exposure for Practices and Games Within Youth Tackle and Flag Football Athletes (n = 477)[a]

Outcome	Estimates[b]	Tackle	Flag
No. of impacts	Average rate of impact per athletic exposure[c]		
	Game	12.97 (11.36 to 14.73)	0.77 (0.53 to 1.06)
	Practice	6.51 (5.75 to 7.37)	0.37 (0.20 to 0.60)
	Rate ratio		
	Game to practice	2.00 (1.74 to 2.29)	2.06 (1.29 to 3.58)
	Probability ≥1 impact		
	Game	0.92 (0.90 to 0.94)	0.53 (0.41 to 0.64)
	Practice	0.92 (0.90 to 0.94)	0.31 (0.18 to 0.45)
Linear acceleration (50%)	Average 50th percentile		
	Game	18.37 (18.17 to 18.57)	16.69 (15.26 to 18.31)
	Practice	18.08 (17.87 to 18.29)	16.19 (15.04 to 17.42)
	Increase in 50th percentile		
	Game vs practice	0.29 (0.09 to 0.49)	0.49 (−1.10 to 2.32)
	Degrees of freedom	2 (2 to 2)	2 (2 to 4)
	Probability 50th percentile greater during games[d]		
	Game ≥practice	1	0.72
Linear acceleration (95%)	Average 95th percentile		
	Game	50.17 (48.57 to 51.77)	32.46 (26.61 to 38.50)
	Practice	50.09 (48.49 to 51.69)	23.69 (18.84 to 29.19)
	Increase in 95th percentile		
	Game vs practice	0.09 (–1.59 to 1.77)	8.69 (1.51 to 15.83)
	Degrees of freedom	3 (2 to 4)	5 (2 to 21)
	Probability 95th percentile greater during games[d]		
	Game ≥ practice	0.54	0.99
High-magnitude impacts (≥40*g*)	Average rate of impact per athletic exposure		
	Game	1.43 (1.24 to 1.64)	—
	Practice	0.70 (0.61 to 0.79)	—

Outcome	**Estimates**[b]	**Tackle**	**Flag**
	Rate ratio		
	Game to practice	2.06 (1.80 to 2.34)	—
	Probability ≥1 impact		
	Game	0.75 (0.70 to 0.79)	—
	Practice	0.50 (0.45 to 0.54)	—

[a] Estimates and comparisons were for those aged 6 to 14 years, by outcome variable (number of impacts, 50th percentile of linear acceleration, 95% percentile of linear acceleration, and high-magnitude impacts [≥40*g*]), in New York, 2017 and 2018. Data in parentheses are 95% CI. Dashes indicate that models were not stable and results were not calculated.

[b] Estimates may differ slightly when the data are stratified by type of football played (ie, tackle, flag) and games versus practices.

[c] Athletic exposure is defined as a youth football practice or game.

[d] Reported value is the proportion of posterior samples in which estimate for games exceeded that for practice. Therefore, no CI is reported.