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Youth Tackle Football Head-Impact Estimation by Players and Parents: Is the Perception the Reality?

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Context: With growing concerns surrounding exposure to head impacts in youth tackle football, players and parents must understand the exposure level when assenting and consenting to participate.

Objective: To determine whether youth football players and parents could estimate on-field head-impact frequency, severity, and location.

Design: Prospective cohort study.

Setting: Football field.

Patients or Other Participants: We administered a 10-question head-impact estimation tool to parents (n = 23; mean age = 36.5 years [95% CI = 31.7, 37.3 years]) and players (n = 16 boys; mean age = 11.1 years [95% CI = 10.3, 11.8 years]).

Main Outcome Measure(s): Player on-field head-impact exposure was captured using the Triax SIM-G system. We determined the accuracy between player and parent estimates relative to on-field head-impact exposures using κ and weighted κ values.

Results: Youth tackle football players and parents did not accurately estimate on-field head-impact frequency (κ range = −0.09 to 0.40), severity (κ range = −0.05 to 0.34), or location (κ range = −0.30 to 0.13). Players and parents overestimated head-impact frequency in practices but underestimated the frequency in games. Both groups overestimated head-impact severity, particularly in games. Most players and parents underestimated the number of head impacts to the top of the head, particularly during practices.

Conclusions: Underestimations of head-impact frequency in games and to the top of the head suggest that informed consent processes aimed at educating players and parents should be improved. Overestimations of head-impact frequency in practices and severity may explain declining rates of youth tackle football participation.

Key Words: mild traumatic brain injury, concussion education, sport policy

Key Points

- Youth tackle football players and parents did not accurately estimate the frequency, severity, or location of head impacts sustained during participation.
- Players and parents need to better understand the frequency of head impacts in games and to the top of the head.
- Overestimations of head-impact exposure may be driving declining youth tackle football participation rates, which warrants further investigation.

Youth tackle football participation has been steadily declining,[1] with an estimated 17.9% decrease between 2009 and 2014. The decline in football enrollment coincides with an increase in the number of news reports linking football and brain injury.[1] A predominate focus of recent news reports has been the increasing concern regarding the risk for long-term negative health outcomes associated with youth tackle football participation,[2] specifically the number and magnitude of head impacts sustained.

Concern over concussion and head-impact exposure has driven a global conversation regarding potential solutions. A wide range of solutions has been suggested, such as increasing the age at which tackling is introduced[3] and implementing rule changes aimed at improving player safety.[4] Recent legislation and sport organizing groups have almost universally mandated annual concussion education requirements with signed acknowledgments, requiring parental informed consent regarding the known risks associated with football participation.[5] In theory, these forms of education and subsequent consent processes provide the information necessary for players and parents to make informed decisions.[6] These educational materials typically address the topic of concussion but rarely provide information regarding the risks associated with repetitive head-impact exposures.

When parents were asked to estimate the number of youth tackle football players out of 100 players who would sustain a concussion during a single season of high school football, 80.5% of parents overestimated the actual concussion risk.[7] True concussion rates in youth tackle football are lower than parents estimated (3% to 5% of players per season) and similar to concussion rates in other boys' youth contact sports, including soccer, ice hockey, lacrosse, and flag football.[8,9] Although the concussion risk is central to football safety debates, many experts point to

Table. Descriptive Information for Youth Tackle Football Players and Parents

Characteristic	Parents (n = 23)	Players (n = 16)
Age, mean (95% CI), y	36.5 (31.7, 37.3)	11.1 (10.3, 11.8)
Combined seasons of tackle football experience, mean (95% CI)	4.9 (0.7, 9.1)	2.4 (0.8, 3.9)
Team, No.		
9U	8	2
10U	9	9
12U[a]	6	5
Season, No.		
2017	11	10
2018	12	6

[a] Data were captured for 2 12U teams, with 1 in each season.

repetitive head-impact exposures as the most important risk factor for negative long-term consequences.[10,11] Players and parents should understand that head-impact exposure is associated with football participation, but whether players and parents can accurately assess this exposure remains unknown.

Overestimations of head-impact exposure may result in unwarranted withdrawal from participation, whereas underestimations might suggest that players and parents are not accurately weighing the risks of youth tackle football participation. Therefore, the purpose of our study was to determine whether player and parent head-impact estimations before a youth tackle football season agreed with on-field head-impact frequency, severity, and location during the season. We hypothesized that players and parents would overestimate the frequency and severity of on-field head impacts but accurately estimate head-impact location.

METHODS

Participants

Male youth tackle football players and parents from 4 teams in a single recreation department in the rural southern United States were invited to participate over the course of 2 football seasons. Descriptive information is presented in the Table. This study was approved by the Institutional Review Board of the University of Georgia. All players assented to be in the study, and at least 1 parent or guardian provided written informed consent.

Head-Impact Estimation

At the beginning of the football season, players and parents were invited to complete a head-impact estimation tool developed by our research team to capture player and parent head-impact estimations. The tool contained 10 items, as follows: 3 related to frequency (Q1–Q3), 3 related to severity (Q4–Q6), and 4 related to location (Q7–Q10). All items and the response options as viewed by the participants are shown in Figures 1 through 3. Items Q2 and Q3, Q5 and Q6, Q7 and Q8, and Q9 and Q10 were identical questions but split between practices and games. The estimation tool was generated by the lead author (J.D.S.) and last author (R.C.L.). Four external researchers with expertise in youth tackle football head-impact exposure reviewed the tool for content validity.

Participants were provided the following operational definition of a *head impact*: "Getting hit in the head can either be when you hit someone else or when someone else hits you." Paper forms were distributed at practices, but participants were allowed to complete the forms at home and return them on a subsequent day. Recruits were excluded if they did not complete at least 30% of the responses. Otherwise, missing responses remained blank and were excluded from the corresponding analyses. Final samples are reported in Figures 1 through 3.

The primary focus of this study was measuring head-impact estimation; however, we did include 2 questions regarding concussion-risk estimation. We asked players and parents: "Do you think [you] [your child] will get a concussion this season?" and "How many players on your [team] [child's team] do you think will be concussed this season?"

Head-Impact Outcomes

Smart Impact Monitors (SIM-G; Triax Technologies) were inserted in headbands or skullcaps and used to collect head-impact biomechanics data for all players. All parents had 1 child instrumented. The SIM-G sensor consists of a triaxial accelerometer and triaxial gyroscope for measuring linear and rotational acceleration, respectively. Previous researchers[12,13] have used the SIM-G sensor to record on-field head-impact biomechanics. The SIM-G validation studies have demonstrated mixed results regarding impact location, linear acceleration, and rotational acceleration validity.[14–16] However, the validity of SIM-G is similar to that of other on-field head-impact biomechanics systems,[17,18] and we chose to bin our outcomes into categories to account for some of the measurement variability. We selected the SIM-G system because our study included both helmeted and nonhelmeted participants and was part of a larger study in which head-impact exposures in youth tackle and flag football were examined.[19]

Transformation of the SIM-G linear acceleration data to the head center of gravity was described in an earlier investigation.[19,20]

Procedures

Tackle football players were fitted with a specific Triax SIM-G sensor and headband or skullcap unique to each participant. All participants wore their assigned SIM-G throughout the season (full-padded practices, scrimmages, and games), with the device placed below the external occipital protuberance. A research team member was present to distribute and collect SIM-Gs before and after each session; ensure sustained proper placement and fit; and record each event's start and end times, water breaks, injury time-outs, any miscellaneous pauses in play, and if athletes removed or tampered with their devices.[19]

Data Reduction

Head-impact data went through a multistep cleaning process before being analyzed.[19] We first removed all impacts that were deemed transient or invalid by the Triax proprietary filters. Researcher-recorded time stamps for start and end times, water breaks, injury time-outs, and any miscellaneous pauses in play were used to remove false-positive head impacts or impacts unrelated to youth tackle football. Head impacts were not verified on video. We also applied a high-frequency threshold (the sum of median impacts per session and third-quartile impacts per session)

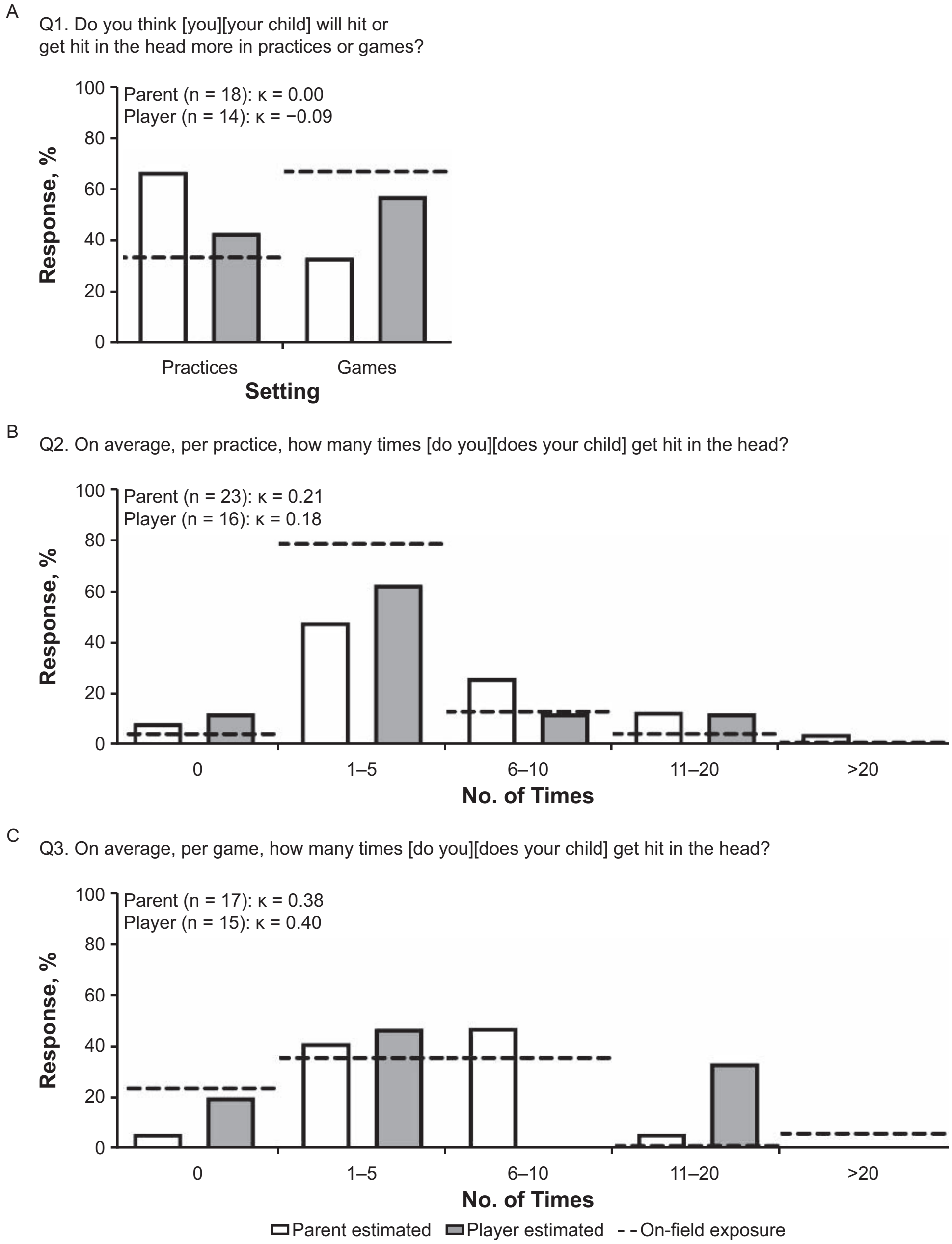

Figure 1. A–C. Head-impact frequency. The percentage of players and parents estimating each response option (bars) is shown relative to the percentage of players in each category based on their on-field head-impact exposure (dashed line). Bars below the dashed line indicate an underestimation relative to the on-field head-impact outcomes. Bars above the dashed line indicate an overestimation relative to the on-field head-impact outcomes. Weighted κ values represent agreement between the player's or parent's estimation relative to how the matched player or parent was categorized based on the on-field outcomes.

to remove likely fraudulent impacts due to frequent SIM-G removal or improper wearing. We flagged players whose impacts in a single session exceeded the high-frequency threshold and removed these data from the analysis dataset. Sessions were classified as described in a previous study.[19] Players were excluded from practice and game analyses if they did not participate in at least 30% of all events.

Our goal was to compare the on-field head-impact outcomes with the head-impact estimations of players and parents. Thus, each player's on-field head-impact outcomes were converted to match a head-impact estimation response category as follows.

Frequency. For Q1, we summed the total number of head impacts in practices and games separately and then divided these totals by the number of corresponding events recorded during the season for each player to normalize the outcomes to each player's participation. For Q2 and Q3, we binned each player's per-practice and per-game head-impact frequencies into the following categories: 0 times, 1 to 5 times, 6 to 10 times, 11 to 20 times, and $>$20 times. Head-impact frequencies per event that fell between response options were rounded to the nearest category.

Severity. For Q4, we computed the average linear and rotational acceleration for each player separately for practice and game head impacts to compare head-impact severity

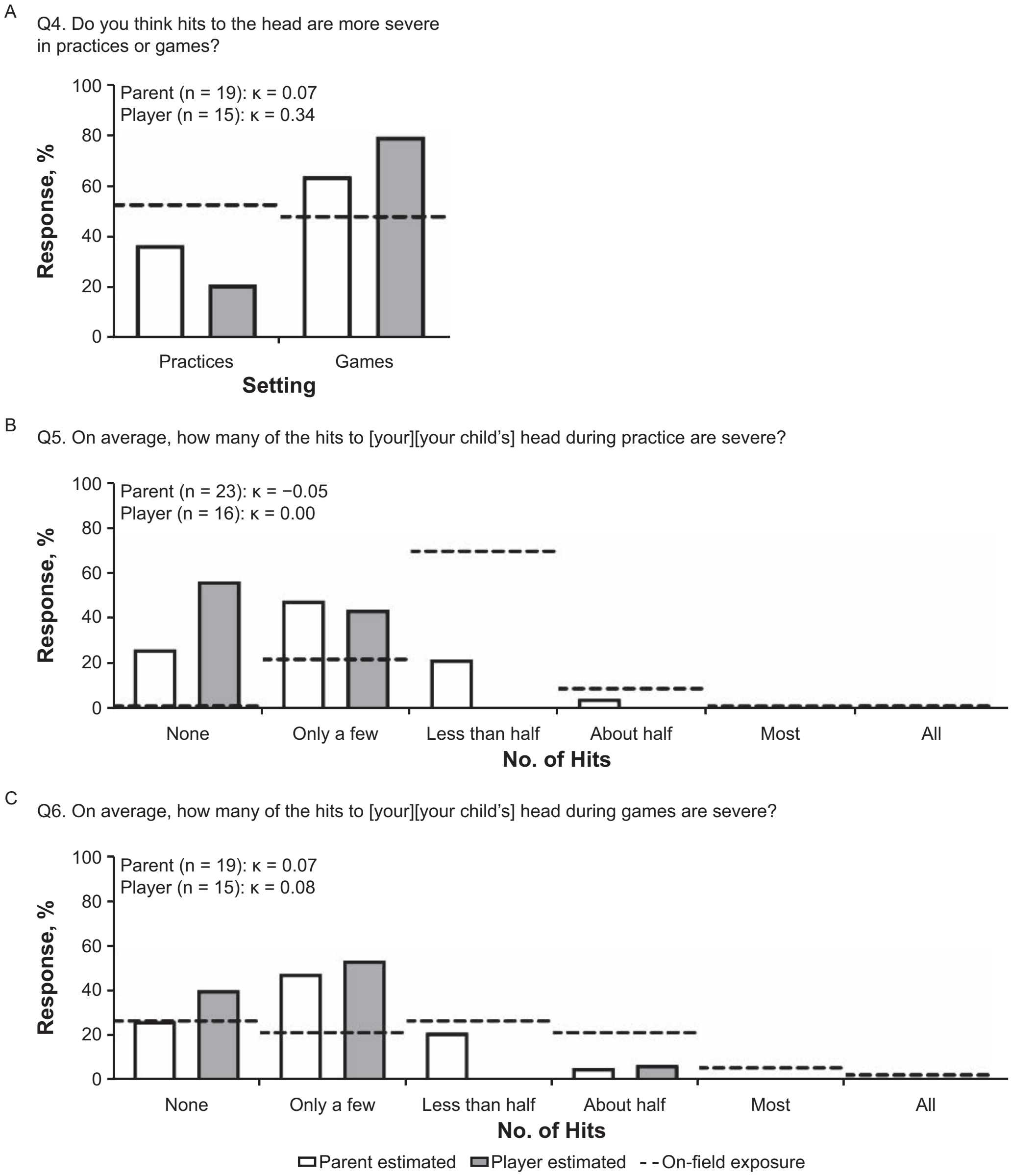

Figure 2. A–C. Head-impact severity. The percentage of players and parents estimating each response option (bars) is shown relative to the percentage of players in each category based on their on-field head-impact exposure (dashed line). Bars below the dashed line indicate an underestimation relative to the on-field head-impact outcomes. Bars above the dashed line indicate an overestimation relative to the on-field head-impact outcomes. Weighted κ values represent agreement between the player's or parent's estimation relative to how the matched player or parent was categorized based on the on-field outcomes.

between event types. For Q5 and Q6, head impacts with a linear acceleration of $\geq 40g$ were classified as severe, as this cutoff has been used in several earlier youth football studies[21–23] and approximates "very high" maximum principal strain in youth brain modelling.[24,25] We then categorized each player's percentage of severe head impacts into estimation response options as follows: *none of the hits are severe* (0%), *only a few of the hits are severe* (1%–19%), *less than half of the hits are severe* (20%–39%), *about half of the hits are severe* (40%–59%), *most of the hits are severe* (60%–89%), or *all of the hits are severe* (90%–100%). We did not provide an operational definition of *severe* to players and parents.

Location. For Q7 and Q8, we categorized head-impact outcomes into response options as follows: *none of the hits are to the top of my head* (0%), *only a few of the hits are to the top of my head* (1%–19%), *less than half of the hits are to the top of my head* (20%–39%), *about half of the hits are to the top of my head* (40%–59%), *most of the hits are to the top of my head* (60%–89%), or *all of the hits are to the top of my head* (90%–100%). For Q9 and Q10, we calculated the percentage of head impacts that fell into each location category (front, back, sides, and top) to identify each player's most common location.

The accuracy of player and parent estimates was calculated and supplemented with Cohen κ (nominal outcomes: Q1 and Q4) and weighted κ (ordinal outcomes: Q2, Q3, Q5, Q6, Q7, Q8, Q9, and Q10) coefficients to provide numerical context for accuracy. For weighted κ analyses, we weighted proximate responses sequentially (ie, *none of the hits are severe* versus *only a few of the hits are severe*). Concussion-risk estimates are presented

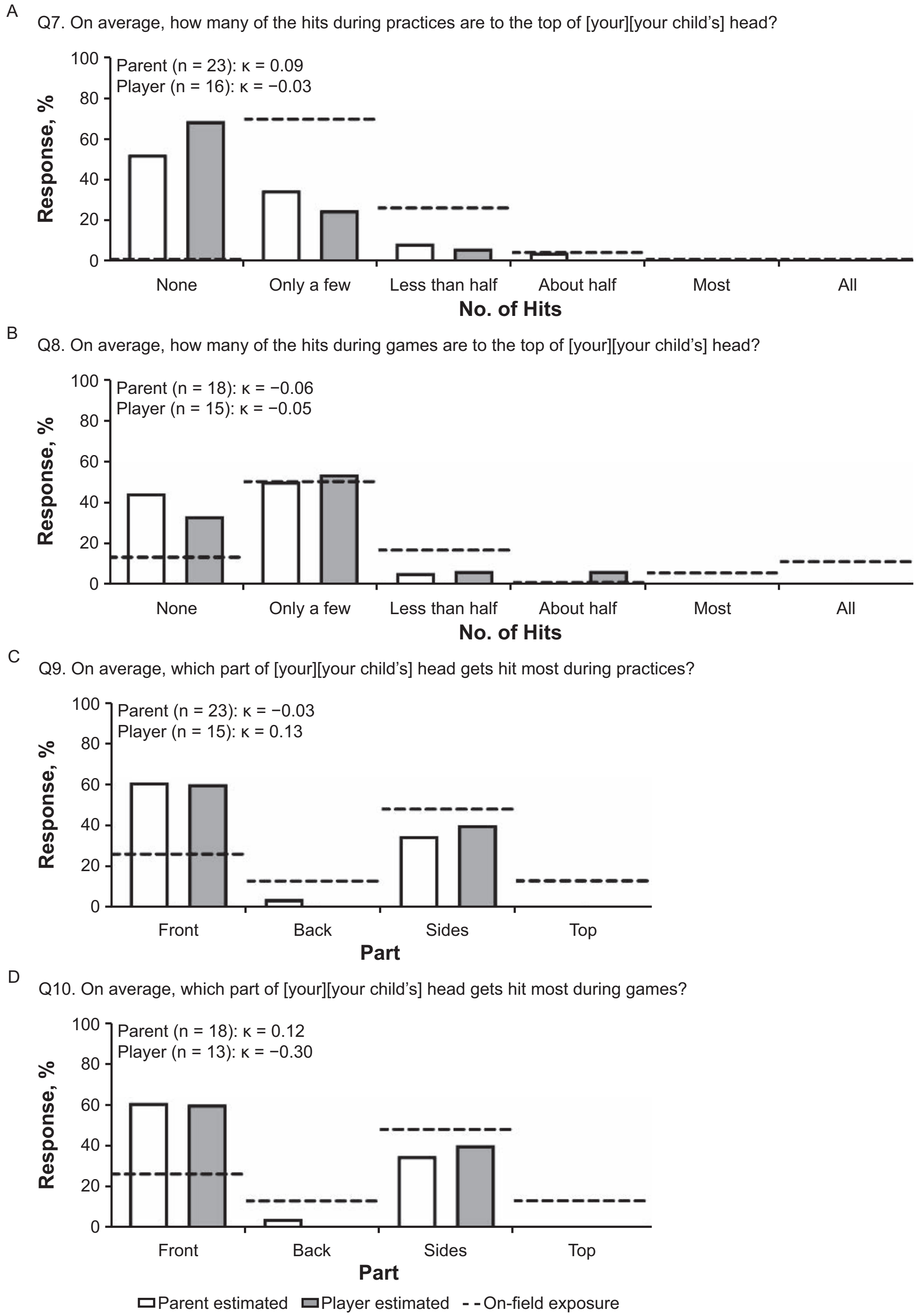

Figure 3. A–D. Head-impact location. The percentage of players and parents estimating each response option (bars) is shown relative to the percentage of players in each category based on their on-field head-impact exposure (dashed line). Bars below the dashed line indicate an underestimation relative to the on-field head-impact outcomes. Bars above the dashed line indicate an overestimation relative to the on-field head-impact outcomes. Weighted κ values represent agreement between the player's or parent's estimation relative to how the matched player or parent was categorized based on the on-field outcomes.

descriptively. We applied the following criteria to interpret the level of agreement for Cohen κ values: *none* (0–0.20), *minimal* (0.21–0.39), *weak* (0.40–0.59), *moderate* (0.60–0.79), *strong* (0.80–0.90), and *almost perfect* (>0.90).[26] We used SPSS (version 26.0; IBM Corp) for statistical analysis.

RESULTS

A total of 19 players and 27 parents initially completed the head-impact estimation tool and provided corresponding head-impact data. Three players and four parents were excluded because of insufficient responses. One player was excluded from the game analyses because of insufficient participation (<30%), 1 parent was excluded from the practice analyses because of the corresponding child's insufficient practice participation, and 4 parents were excluded from the game analyses because of insufficient game participation for their corresponding child. Thus, the final sample consisted of 16 players and 23 parents. No players or parents participated in both seasons. No player had >1 parent complete the head-impact estimation tool, and no parent responded for >1 child. Descriptive information is presented in the Table. The accuracy of player and parent estimates along with Cohen κ and weighted κ coefficients are presented in Figures 1 through 3.

Youth tackle football players and parents did not accurately estimate on-field head-impact frequency (κ range = −0.09 to 0.40; Figure 1), severity (κ range = −0.05 to 0.34; Figure 2), or location (κ range = −0.30 to 0.13; Figure 3). The agreement of κ values ranged from *none* to *weak*.

When asked "Do you think [you] [your child] will get a concussion this season?" all players and parents responded *no*. When asked "How many players on your [team] [child's team] do you think will be concussed this season?" 35.7% (n = 5/14) of players responded *0*, 42.9% (n = 6/14) responded *1*, and 21.4% (n = 3/14) responded *2*. Parents' responses were slightly more distributed, with 8.7% (n = 2/23) responding *0*, 52.2% (n = 12/23) responding *1*, 17.4% (n = 4/23) responding *2*, 13.0% (n = 3/23) responding *4*, and 8.7% (n = 2/23) responding *5*. No concussive events were recorded for our sample.

DISCUSSION

Players and parents did not accurately characterize head-impact frequency, severity, or location during a single season of youth tackle football. This discrepancy suggests that players and parents do not accurately characterize the level of exposure associated with youth tackle football.

Frequency

Players and parents overestimated the head-impact frequency in practices but underestimated the frequency in games (Figure 1). We asked players and parents to compare (Q1) and quantify head-impact frequency during practices (Q2) and games (Q3). Most parents (66.7%) said that head impacts would be more frequent during practices, whereas only 33.3% of players actually sustained most of their head impacts in practices.[27] Interestingly, players more closely estimated their true practice head-impact frequency than parents did (Figure 1A and B). Through their actual on-field experiences, players may gain a better appreciation for the frequency of head impacts. Parents' estimations may be less accurate because they are often on the sideline observing the activity. It was outside the scope of our study to determine how players and parents formed their head-impact exposure estimations, but researchers have suggested that parents may base concussion estimation risks on their observations, their own previous experiences with sport, or media influences.[28] Future researchers should determine which sources inform layperson estimations of head-impact exposure. Twelve players reported participation in at least 1 previous season of tackle football, which may have served as a reference point when estimating head-impact exposure. Earlier authors[29] proposed that the Triax SIM-G system may overestimate head-impact frequency; however, we sought to compensate for this by using more stringent timestamp filtering than prior investigators have used, and our results were similar to those of other estimates[21,30] of head-impact frequency in youth tackle football. Furthermore, we have no reason to believe this would affect game-to-practice referenced comparisons (Q1).

Severity

Players and parents overestimated head-impact severity, particularly in games. Similar to previous studies,[19,31] our on-field data captured from players throughout the season indicated that head-impact severity did not differ between practices and games. Yet most players (78.6%, n = 11/14) and parents (63.2%, n = 12/19) estimated that games would yield more severe head impacts (Figure 2A). Players and parents may expect physicality and risk to be higher during competition, but the actual head-impact exposures were similar across event types. Media attention surrounding football often focuses on more severe collisions, specifically those that occurred during televised games. When penalties are involved, these severe collisions are often replayed several times, with close focus on the head-impact severity. Football games are televised, whereas practices mostly are not, which may lead players and parents to focus more on the risk during games.

We categorized head impacts using a cutoff of 40*g*, but no perfect operational definition of *head-impact severity* categorization exists. We chose this threshold because it has been widely used in youth tackle football, allowing for comparisons with other studies, and because it approximates high or very high mean principal strain values using finite element modeling to model a youth brain,[24,25] but other estimates of concussion risk indicate potentially higher cutoffs.[32,33] In recent work, researchers[32,34,35] have suggested that injury thresholds are not as simple as prescribing cutoffs across all athletes but are also based more on each player's head-impact exposure and relative head-impact severity. Our results are similar to those of Savino et al,[36] who found that perceived head-impact severity by youth and high school tackle football players was only weakly correlated with on-field head-impact kinematic outcomes. Nonetheless, they did not discern whether players over- or underestimated head-impact severity, only that players did not accurately estimate their head-impact severity in a single season.

Location

Most players and parents underestimated the number of head impacts to the top of the head, particularly during practices (Figure 3A). Among our sample, 68.8% (n = 11/16) of players and 52.2% (n = 12/23) of parents thought that none of the head impacts sustained would be to the top of the head. However, no single youth tackle football player completed the entire season without sustaining at least 1 impact to the top of the head. Most players had only a few (1%–19%) or fewer than half (20%–39%) of their head impacts to the top of the head. Impacts to the top of the head are considered dangerous because spinal loading transmitted through the top of the head while the cervical spine is in a flexed position may pose a catastrophic threat to the spinal cord.[37] Cervical forward flexion decreases the natural lordosis of the cervical spine such that the vertebral bodies are stacked on one another in a column formation, the cervical musculature is more relaxed, and the vertebrae more easily collapse and fracture, impinging the spinal cord.[37] Top-of-the-head impacts are between 2.4 and 8.5 times more severe than those at other locations[31] and are more likely to result in loss of consciousness.[38]

Players and parents estimated that most head impacts would occur to the front of the head (Figure 3C and D). However, our on-field data showed that side impacts were the most common, followed by front, top, and back impacts. In contrast, other authors[38,39] showed that front impacts were the most common but also that head impacts were considerably distributed across locations. Players and parents may think that most collisions occur with 2 opponents approaching face to face, resulting in a front impact. Yet the sport of football is much more dynamic than uniplanar collisions, and not all head impacts occur to the front of the head.

Concussion-Risk Estimation

No players or parents estimated that they or their child would sustain a concussion in the upcoming season. Previous researchers[9,40] demonstrated that approximately 3% to 5% of players on a youth tackle football team will sustain a concussion in a single season. It is plausible that our findings reveal a pattern of optimism bias among youth tackle football players and parents, which has been identified in college-aged football players.[41] Players and parents who elect to participate in youth tackle football may hold a more optimistic view of the concussion risk. Research should be done to compare these estimations among sports with various concussion risks, such as flag football or soccer. It is also plausible that, with rates as low as 3% to 5%, our participants responded unanimously this way because the odds are more likely that players will not sustain a concussion in a single season.

In contrast to their responses regarding their risk or their child's risk, players and parents had less optimistic responses to how many players on their team would sustain a concussion. The studied teams carried rosters of approximately 25 players. Applying published concussion rates for youth tackle football[9,40] to a team of 20 to 25, we should expect 0.60 to 0.75 concussions per team per year (ie, 1.2 to 1.5 per every 2 seasons). Most players and parents estimated that $\geq$1 player on their team would sustain a concussion, which suggests a slight overestimation of injury risk. Our results are similar to but not quite as pronounced as those reported by Chrisman et al.[7]

Limitations

This study had limitations. No true criterion standard instrumentation exists for capturing on-field head-impact exposures. Some notable concerns with the Triax SIM-G device should be considered. All head-impact systems exhibit considerable variability in their ability to capture head-impact frequency, severity, and location. We sought to account for some of this variability by categorizing both on-field and estimated head-impact outcomes in response options. Earlier investigators[29] have also reported variability in head-impact frequency measures. We sought to reduce this limitation by recording and removing data captured during water breaks, injury time-outs, and any miscellaneous pauses. Furthermore, our conservative data-cleaning procedures were meant to exclude spurious impacts.[19] In addition, the Triax SIM-G uses a threshold of 14*g*, whereas players and parents may have higher or lower thresholds for what they consider a head impact. The Triax SIM-G system relies on adult male anthropometrics to convert raw accelerometry data to the head center of mass and, therefore, may not be as accurate in youth athletes with smaller head sizes and masses. The head-impact estimation tool was administered at the beginning of the season. Player and parent accuracy may improve over the course of a season after participating in or observing a season's worth of head impacts, which would be an interesting focus for future examination. However, most players and parents had experience with tackle football before our study. Finally, our sample size was small, and this research question should be explored in larger samples.

CONCLUSIONS

Understanding whether athletes and parents accurately appraise risk is of upmost importance. Overall, we found that youth tackle football players and parents did not accurately estimate the frequency, severity, or location of head impacts sustained during participation. Players and parents need to better understand the frequency of head impacts in games and to the top of the head. Overestimations in head-impact exposure may be driving declining youth tackle football participation rates, which warrant further evaluation.

REFERENCES

1. Feudtner C, Miles SH. Traumatic brain injury news reports and participation in high school tackle football. *JAMA Pediatr*. 2018;172(5): 492–494. doi:10.1001/jamapediatrics.2017.5242
2. Alosco ML, Stern RA. Youth exposure to repetitive head impacts from tackle football and long-term neurologic outcomes: a review of the literature, knowledge gaps and future directions, and societal and clinical implications. *Semin Pediatr Neurol*. 2019;30:107–116. doi:10.1016/j.spen.2019.03.016
3. Alosco ML, Kasimis AB, Stamm JM, et al. Age of first exposure to American football and long-term neuropsychiatric and cognitive outcomes. *Transl Psychiatry*. 2017;7(9):e1236. doi:10.1038/tp.2017.197
4. Ocwieja KE, Mihalik JP, Marshall SW, Schmidt JD, Trulock SC, Guskiewicz KM. The effect of play type and collision closing distance on head impact biomechanics. *Ann Biomed Eng*. 2012; 40(1):90–96. doi:10.1007/s10439-011-0401-7
5. Di Lu L, Heinze KL. Sport policy institutionalization: examining the adoption of concussion legislation across states. *J Sport Manage*. 2019;33(6):493–505. doi:10.1123/jsm.2018-0330
6. Lerner A, Fost N. Informed consent for youth tackle football: implications of the AAP policy statement. *Pediatrics*. 2019;144(5): e20191985. doi:10.1542/peds.2019-1985
7. Chrisman SPD, Whitlock KB, Kroshus E, Schwien C, Herring SA, Rivara FP. Parents' perspectives regarding age restrictions for tackling in youth football. *Pediatrics*. 2019;143(5):e20182402. doi:10.1542/peds.2018-2402
8. Bretzin AC, Covassin T, Fox ME, et al. Sex differences in the clinical incidence of concussions, missed school days, and time loss in high school student-athletes, part 1. *Am J Sports Med*. 2018; 46(9):2263–2269. doi:10.1177/0363546518778251
9. Chrisman SPD, Lowry S, Herring SA, et al. Concussion incidence, duration, and return to school and sport in 5- to 14-year-old American football athletes. *J Pediatr*. 2019;207:176–184. doi:10.1016/j.jpeds.2018.11.003

10. 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. doi:10.1089/neu.2016.4413
11. Bazarian JJ, Zhu T, Zhong J, et al. Persistent, long-term cerebral white matter changes after sports-related repetitive head impacts. *PLoS One*. 2014;9(4):e94734. doi:10.1371/journal.pone.0094734
12. Lamond LC, Caccese JB, Buckley TA, Glutting J, Kaminski TW. Linear acceleration in direct head contact across impact type, player position, and playing scenario in collegiate women's soccer players. *J Athl Train*. 2018;53(2):115–121. doi:10.4085/1062-6050-90-17
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. doi:10.1080/15438627.2016.1230549
14. Kieffer EE, Begonia MT, Tyson AM, Rowson S. A two-phased approach to quantifying head impact sensor accuracy: in-laboratory and on-field assessments. *Ann Biomed Eng*. 2020;48(11):2613–2625. doi:10.1007/s10439-020-02647-1
15. Tyson AM, Duma SM, Rowson S. Laboratory evaluation of low-cost wearable sensors for measuring head impacts in sports. *J Appl Biomech*. 2018;34(4):320–326. doi:10.1123/jab.2017-0256
16. Cecchi NJ, Monroe DC, Oros TJ, Small SL, Hicks JW. Laboratory evaluation of a wearable head impact sensor for use in water polo and land sports. *Proc Inst Mech Eng P*. 2020;234(2):162–169. doi:10.1177/1754337120901974
17. Cummiskey B, Schiffmiller D, Talavage TM, et al. Reliability and accuracy of helmet-mounted and head-mounted devices used to measure head accelerations. *Proc Inst Mech Eng P*. 2016;231(2):144–153. doi:10.1177/1754337116658395
18. Wu LC, Nangia V, Bui K, et al. In vivo evaluation of wearable head impact sensors. *Ann Biomed Eng*. 2016;44(4):1234–1245. doi:10.1007/s10439-015-1423-3
19. Lynall RC, Lempke LB, Johnson RS, Anderson MN, Schmidt JD. A comparison of youth flag and tackle football head impact biomechanics. *J Neurotrauma*. 2019;36(11):1752–1757. doi:10.1089/neu.2018.6236
20. Yoganandan N, Pintar FA, Zhang J, Baisden JL. Physical properties of the human head: mass, center of gravity and moment of inertia. *J Biomech*. 2009;42(9):1177–1192. doi:10.1016/j.jbiomech.2009.03.029
21. Waltzman D, Sarmiento K, Devine O, et al. Head impact exposures among youth tackle and flag American football athletes. *Sports Health*. 2021;13(5):454–462. doi:10.1177/1941738121992324
22. Campolettano ET, Gellner RA, Rowson S. High-magnitude head impact exposure in youth football. *J Neurosurg Pediatr*. 2017;20(6):604–612. doi:10.3171/2017.5.PEDS17185
23. Daniel RW, Rowson S, Duma SM. Head impact exposure in youth football. *Ann Biomed Eng*. 2012;40(4):976–981. doi:10.1007/s10439-012-0530-7
24. Cournoyer J, Karton C, Koncan D, Gilchrist MD, Cantu RC, Hoshizaki TB. Brain trauma exposure for American tackle football players 5 to 9 and 9 to 14 years of age. *J Biomech*. 2021;127:110689. doi:10.1016/j.jbiomech.2021.110689
25. Miller LE, Urban JE, Kelley ME, et al. Evaluation of brain response during head impact in youth athletes using an anatomically accurate finite element model. *J Neurotrauma*. 2019;36(10):1561–1570. doi:10.1089/neu.2018.6037
26. McHugh ML. Interrater reliability: the kappa statistic. *Biochem Med (Zagreb)*. 2012;22(3):276–282.
27. Sarmiento K, Waltzman D, Devine O, et al. Differences in head impact exposures between youth tackle and flag football games and practices: potential implications for prevention strategies. *Am J Sports Med*. 2021;49(8):2218–2226. doi:10.1177/03635465211011754
28. Taranto E, Fishman M, Garvey K, Perlman M, Benjamin HJ, Ross LF. Public attitudes and knowledge about youth sports participation and concussion risk in an urban area. *J Natl Med Assoc*. 2018;110(6):635–643. doi:10.1016/j.jnma.2018.10.001
29. Patton DA, Huber CM, McDonald CC, Margulies SS, Master CL, Arbogast KB. Video confirmation of head impact sensor data from high school soccer players. *Am J Sports Med*. 2020;48(5):1246–1253. doi:10.1177/0363546520906406
30. Dorman JC, Poel DN, Valentine VD, Munce TA. Head impact exposure of a youth football team over eight consecutive seasons. *Med Sci Sports Exerc*. 2022;54(1):3–11. doi:10.1249/MSS.0000000000002756
31. Mihalik JP, Bell DR, Marshall SW, Guskiewicz KM. Measurement of head impacts in collegiate football players: an investigation of positional and event-type differences. *Neurosurgery*. 2007;61(6):1229–1235. doi:10.1227/01.neu.0000306101.83882.c8
32. Campolettano ET, Gellner RA, Smith EP, et al. Development of a concussion risk function for a youth population using head linear and rotational acceleration. *Ann Biomed Eng*. 2020;48(1):92–103. doi:10.1007/s10439-019-02382-2
33. Campolettano ET, Gellner RA, Sproule DW, Begonia MT, Rowson S. Quantifying youth football helmet performance: assessing linear and rotational head acceleration. *Ann Biomed Eng*. 2020;48(6):1640–1650. doi:10.1007/s10439-020-02505-0
34. Stemper BD, Shah AS, Harezlak J, et al; CARE Consortium Investigators. Comparison of head impact exposure between concussed football athletes and matched controls: evidence for a possible second mechanism of sport-related concussion. *Ann Biomed Eng*. 2019;47(10):2057–2072. doi:10.1007/s10439-018-02136-6
35. Rowson S, Campolettano ET, Duma SM, et al. Accounting for variance in concussion tolerance between individuals: comparing head accelerations between concussed and physically matched control subjects. *Ann Biomed Eng*. 2019;47(10):2048–2056. doi:10.1007/s10439-019-02329-7
36. Savino AK, Huang L, Yang J, Pizzimenti NM, McCarthy MT, Rose SC. Head impact burden differs between seasons in youth and high school US football players. *Ann Biomed Eng*. 2020;48(12):2763–2771. doi:10.1007/s10439-020-02548-3
37. Swartz EE, Boden BP, Courson RW, et al. National Athletic Trainers' Association position statement: acute management of the cervical spine-injured athlete. *J Athl Train*. 2009;44(3):306–331. doi:10.4085/1062-6050-44.3.306
38. Kerr ZY, Collins CL, Mihalik JP, Marshall SW, Guskiewicz KM, Comstock RD. Impact locations and concussion outcomes in high school football player-to-player collisions. *Pediatrics*. 2014;134(3):489–496. doi:10.1542/peds.2014-0770
39. Kelley ME, Kane JM, Espeland MA, et al. Head impact exposure measured in a single youth football team during practice drills. *J Neurosurg Pediatr*. 2017;20(5):489–497. doi:10.3171/2017.5.PEDS16627
40. Dompier TP, Kerr ZY, Marshall SW, et al. Incidence of concussion during practice and games in youth, high school, and collegiate American football players. *JAMA Pediatr*. 2015;169(7):659–665. doi:10.1001/jamapediatrics.2015.0210
41. Baugh CM, Kroshus E, Meehan WP III, McGuire TG, Hatfield LA. Accuracy of US college football players' estimates of their risk of concussion or injury. *JAMA Netw Open*. 2020;3(12):e2031509. doi:10.1001/jamanetworkopen.2020.31509

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