Clinical Neurology and Neurosurgery 118 (2014) 1–4

Contents lists available at ScienceDirect

Clinical Neurology and Neurosurgery

journal homepage: www.elsevier.com/locate/clineuro

Frequency, magnitude, and distribution of head impacts in Pop Warner football: The cumulative burden

Ricky H. Wong[a,*], Andrew K. Wong[b,1], Julian E. Bailes[b,1]

[a] Section of Neurosurgery, University of Chicago, 5841 S. Maryland Avenue MC3026, Chicago 60637, USA
[b] Department of Neurosurgery, North Shore University Health System, 2650 Ridge Avenue, Evanston 60201, USA

ARTICLE INFO

Article history:
Received 9 August 2013
Received in revised form 28 October 2013
Accepted 29 November 2013
Available online 15 December 2013

Keywords:
Chronic traumatic encephalopathy
Head impact
Pop Warner football
Traumatic brain injury
Youth football

ABSTRACT

Background: A growing body of research suggests that subconcussive head impacts or repetitive mild Traumatic Brain Injury (mTBI) can have cumulative and deleterious effects. Several studies have investigated head impacts in football at the professional, collegiate, and high school levels, in an attempt to elucidate the biomechanics of head impacts among football players. Youth football players, generally from 7 to 14 years of age, constitute 70% of all football players, yet burden of, and susceptibility to, head injury in this population is not well known.
Methods: A novel impact sensor utilizing binary force switches (Shockbox®) was used to follow an entire Pop Warner football team consisting of twenty-two players for six games and five practices. The impact sensor was designed to record impacts with linear accelerations over 30*g*. In addition, video recording of games and practices were used to further characterize the head impacts by type of position (skilled versus unskilled), field location of impact (open field versus line of scrimmage), type of hit (tackling, tackled, or hold/push), and whether the impact was a head-to-head impact or not.
Results: We recorded a total of 480 head impacts. An average of 21.8 head impacts occurred per practice, while 61.8 occurred per game. Players had an average of 3.7 head impacts per game and 1.5 impacts per practice ($p < 0.001$). The number of high magnitude head impacts (>80*g*) was 11. Two concussions were diagnosed over the course of the season. However, due to technical reasons the biomechanics of those hits resulting in concussions were not captured.
Conclusion: Despite smaller players and slower play when compared to high school, collegiate or professional players, those involved in youth football sustain a moderate number of head impacts per season with several high magnitude impacts. Our results suggest that players involved in open-field, tackling plays that have head-to-head contact sustain impacts with the highest linear accelerations. Our data supports previously published data that suggests changes to the rules of play during practice can reduce the burden of hits.

1. Introduction

Recent efforts have been focused on the prevention of the acute, subacute, and chronic effects of brain injury in sports and, accordingly, the reduction of concussive and sub-concussive hits, as well as their cumulative impact [1–10]. As such, increasing interest has been given to the consequences of head impacts not only in professional level athletes, but also at the collegiate and high school levels [11–17]. As yet, few studies have investigated the burden of head impacts among pre-high school, youth football players.

In the United States, there are approximately 3.5 million youth football players, representing nearly 70% of all organized football. Recently, Daniel et al. utilized accelerometers installed in football helmets to quantify and qualify the number of hits sustained in youth football [18]. Although only seven players were studied, there was documentation of an average of 107 hits per player per season. Most of those hits (59%) occurred during practice. In addition, higher magnitude impacts were associated more with practices rather than games. This provided opportunity to alter practice rules to effect a change in both the frequency and magnitude of head impacts in youth football. Several youth football leagues subsequently altered their practice structure in an attempt to reduce the frequency and severity of head impacts. In a follow-up study, Cobb et al. followed three youth football teams and found statistically significant reductions in both the frequency and magnitude of head impacts occurring during practice in the team that adopted practice changes [19]. Analysis of head impacts during games across those three teams did not yield any significant differences in head impacts.

* Corresponding author. Tel.: +1 773 702 2123.
E-mail address: wong.ricky@gmail.com (R.H. Wong).
1 Tel.: +1 847 570 1440.

0303-8467/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.clineuro.2013.11.036

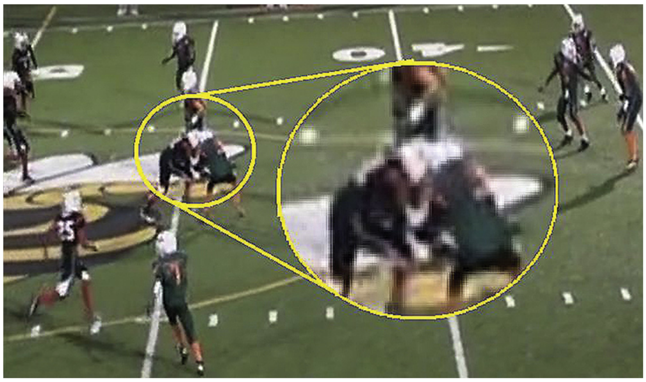

Fig. 1. Video capture of head impact.

Pop Warner football was one of the first youth football league to implement practice changes. In the present study, we followed an entire team of Pop Warner youth football players in order to elucidate the frequency and magnitude of head impacts in youth football and to further characterize those hits.

2. Methods

During the 2012 football season, an entire Pop Warner football team consisting of 22 youth football players of the "Junior Midgets" class was recruited to participate in this observational study. The necessary informed consent was obtained from the players and parents involved. All players wore Xenith X2 (Xenith LLC, Lowell, MA) youth helmets. A novel, non-accelerometer based impact sensor (Shockbox Impact Alert Sensors, Impakt Protective Inc., Canada) was installed at the inner vertex of the football helmets. Each player received a unique identifier that allowed collection of head impact data specific to the player. Their play was followed over the course of eleven play sessions consisting of six games and five practices.

The impact sensor used in this study utilizes four binary force switches that replace the traditional accelerometers used in previous studies. Differential voltage activation of each force switch on impact is recorded and sent via Bluetooth® to a smartphone where a resultant linear acceleration is determined using a helmet-specific algorithm. These binary force switches have been shown to measure accelerations of head impacts with an average error of 8.9% in a limited study [20]. The sensors are programmed to record impacts that register linear accelerations greater than 30*g*. As the device is a commercially available product, designed for general use and not necessarily for research purposes, the sensor threshold is substantially different in previous studies of head impact exposure.

Head impact data, including magnitude, frequency, and site of impact were recorded. It is common for players to play multiple positions at the youth football level, though they generally remained in either skilled or unskilled roles. Unskilled positions included defensive and offensive linemen, while skilled positions included all other positions. In youth football, not every player participates in every session; therefore final calculations of hit counts were based on per session (either game or practice) analysis.

Video recording was routinely made of practices and games for the purposes of training and this data was used to further characterize the hits (Fig. 1). Film of 3 games and 2 practices were available for review. Of the total 480 hits recorded by impact sensors, 138 were captured on video. During video analysis, hits were classified by location on the field (at the line of scrimmage or in the open field), type of hit (player was tackling, being tackled, or pushed/blocked), and whether there was head-to-head contact.

Table 1
Player and head impact characteristics.

Players	Total participants	22
	Position	
	Skilled	13
	Unskilled	9
Average age	12.7 years (range: 12–13)	
Average weight	129.4 pounds (range: 90.6–161.5)	
Hits	Total hits recorded	480
	Event	
	Games	109
	Practices	371
	Position	
	Skilled	300
	Unskilled	180

2.1. Statistical analysis

Paired *t*-test was used to determine the significance in hits per practice versus hits per game. In order to determine the sample size necessary to power the subgroup analysis performed using video recordings, a difference of 5*g* was used as the threshold for clinical significance, while α and β were set at 0.05 and 0.2, respectively.

3. Results

Through the course of this analysis (six games, five practices), 22 players were followed (Table 1). Total head impacts recorded was 480. The mean linear acceleration value was 46.7*g* (range: 30–150*g*, standard deviation: 14*g*). Average head impact that occurred per practice was 21.8 (range: 14–33, standard deviation: 9). Average head impact that occurred per game was 61.8 (range: 27–90, standard deviation: 23). The summary data of head impacts for games and practices was calculated (Table 2). Players were found to sustain 2.2 hits more per game than per practice ($p = 0.001$). Utilizing the high-magnitude impact classification of Daniel et al. (>80*g*), 11 high-magnitude impacts occurred during games, while only two occurred during practices.

Game and practice video analysis during the study allowed for additional characterization of 138 hits (Table 3). Three categories were assessed: position of the player, field location of impact, and the action that led to the hit. With respect to each category, hits were classified as either head-to-head or non-head-to-head.

Two concussions were diagnosed over the course of the season. However, due to technical reasons the biomechanics of those hits resulting in concussions were not captured. Of those two hits, one occurred on a player whose sensor was not charged properly and one occurred when the research assistant and, subsequently, the receiving device was not present.

Table 2
Distribution of head impacts.

	Practice	Game
Average hits/ player	1.5 (range: 0–9, SD: 1.3)	3.7 (range: 0–24, SD: 3.6)
Average acceleration/hit	45.1*g* (range: 30–150, SD: 15)	47.2*g* (range: 30–125, SD: 14)
Average hits/skilled player	1.3 (range: 0–9, SD: 1.4)	3.9 (range: 0–24, SD: 4.3)
Average hits/unskilled player	1.7 (range: 0–7, SD: 1.2)	3.3 (range: 0–12, SD: 1.4)

SD, standard deviation.

Table 3
Characterization of head impacts by video analysis with associated mean and range of linear acceleration values by (a) player position, (b) field location of impact, and (c) type of hit.

(a)	Skilled (83 hits) 47.5g (35–125g)	Unskilled (55 hits) 46.0g (30–100g)	
Head-to-head (67 hits) 48.2g (35–125g)	32 hits 50g (35–125g)	35 hits 46.6g (35–70g)	
Non-head-to-head (71 hits) 45.8g (30–100g)	51 hits 45.9g (35–90g)	20 hits 45.5g (30–100g)	
(b)	Open field (41 hits) 48.8g (35–125g)	Line of scrimmage (97 hits) 46.2g (30–102g)	
Head-to-head	12 hits 55.3g (35–125g)	55 hits 46.6g (35–102g)	
Non-head-to-head	29 hits 46.1g (36–70g)	42 hits 45.6g (30–100g)	
(c)	Tackling (24 hits) 50.6g (35–125g)	Tackled (22 hits) 44.9g (35–70g)	Hold/push (92 hits) 46.5 (30–102g)
Head-to-head	8 hits 56.1g (40–125g)	6 hits 47.3g (40–70g)	53 hits 47.1g (35–102g)
Non-head-to-head	16 hits 47.8g (35–70g)	16 hits 44g (35–65g)	39 hits 45.7 (30–100g)

4. Discussion

There has been a tremendous expansion of our knowledge about concussive injury in athletes during the last decade. We have a better understanding for the potential metabolic and ultrastructural consequences of single impact head injury, and are gaining a greater appreciation that repetitive concussive and subconcussive blows may be important and deleterious in certain individuals [21]. The use of emerging technologies to gain real-time data on sports collisions along with the mandatory use of helmets in American football has allowed for the systematic analysis of injury biomechanics. This new technology has led to a more extensive knowledge of the forces, velocities, accelerations and frequencies of head injuries, which can be applied to football or any other circumstances where repetitive head injury can occur.

The possibility that prior repetitive brain injuries may have lasting effects was reported in a 2005 study on retired National Football League (NFL) players. Guskiewicz et al. found a fivefold increase in the likelihood of developing mild cognitive impairment in those who had a history of three or more concussions, as well as an increase in the development of early onset Alzheimer's disease [22]. Another report from the same group found that a history of three or more concussions was correlated with a threefold increase in the diagnosis of depression during the retirement years when compared to age-matched controls [23]. This led to substantial research into head impacts among collegiate and high school level football players to better characterize the burden of injury in a lifelong player.

It was previously thought that youth football would not have any meaningful cranial impacts due to smaller players, less velocity of impacts, and decreased intensity of play. Youth football players, generally from 7 to 14 years of age, constitute about 70% of all football players and a total of 3.5 million participants. Thus while youth football players may have fewer helmet impacts and lower force hits than their older counterparts, high magnitude impacts may nevertheless occur, and their long-term implications in an exposure paradigm are uncertain. Daniel et al. published data on 7 youth football players [18]. Utilizing an accelerometer-based Head Impact Telemetry (HIT) System that recorded data on impacts with linear accelerations greater than 10g, they found a total of 748 impacts and an average of 107 impacts per player over a season with a number of high-magnitude (>80g) impacts. The linear acceleration average value was 18g. Approximately 85% of the total impacts had linear acceleration values less than 30g. They also found an average of 63 hits per practice and 44 hits per game. This translated into 6.7 hits per player per practice and 5.8 hits per player per game. In addition, higher magnitude impacts, 76% of impacts greater than 40g and 100% of impacts greater than 80g, occurred more commonly during practice.

While the 107 head impacts per player over a season are significantly less than those reported in high school and collegiate athletes, the number of high-magnitude impacts was surprising. This data, along with the prevalence of impacts and, specifically, high-magnitude impacts during practice led to the consideration of various changes in play regulations across the country in youth football leagues. Pop Warner football was one of the first to adopt such policy changes, which included reduced contact during practice sessions. Beginning in the 2012 season, Pop Warner football eliminated head contact when players are separated by 3 yards or more, as well as reduced any contact drills to only one-third of the week by practice time [24].

Recently, Cobb et al. followed three youth football teams over an entire season. One of the three teams adhered to the Pop Warner rule changes. Players on that team experienced 37–46% fewer impacts than the other two teams, though that difference was only statistically significant for one. In both teams without practice changes, the majority of season impacts occurred during practice, which is consistent with the previous report by Daniel et al. This relationship, however, was not seen in the team that adopted practice changes. There, the vast majority of impacts over a season occurred during games. In addition, they found mean linear acceleration of impacts during practices to be 22g, while during games it was 23g, with statistically significant lower linear acceleration values associated with the team that adopted practice rule changes. That team, however, had a significantly lower mean body mass (37.6 kg compared to 50.1 kg and 43.9 kg), which may explain the reduced impact accelerations.

Our study is the first to monitor an entire youth football team for this extent of a season, including games and practices, using in-helmet impact sensors for hit registration and correlation with videotape analysis. Our results demonstrate 1.5 hits occurring per player per practice and 3.7 hits occurring per player per game. The number of hits per player per practice and per game is substantially less than that reported by Daniel et al. This is likely the result of differing thresholds for hit registration. Our non-accelerometer sensor used 30*g* as the threshold, while Daniel et al. used 10*g*. In the latter study, approximately 85% of hits had linear acceleration values below 30*g*. In the study by Cobb et al., approximately 80% of the impacts had linear acceleration values below 30*g*. Therefore it is difficult to compare our absolute hit counts with those of previously published reports. Significantly, however, the number of hits that we recorded during practice was substantially lower than the number that we recorded during games. Across all five groups of youth football players in the literature (four teams and one partial team) that have been followed for hit counts (present report included), only two have had a significantly lower number of hits per session during practice. Both teams adhered to the new practice rule changes of Pop Warner football. This suggests that changes to rules of play can have measurable effects on the number of hits that occur in a play session.

The mean linear acceleration of impacts in our study was 46.7*g*. This is substantially higher than previously reported values, but as with the hit counts, it is significantly skewed by our sensor threshold. By excluding all hits under 30*g*, our sensor would have excluded 80–85% of hits reported in previous studies. As a result, no meaningful comparison can be made. Our linear acceleration values, however, can be used for comparison in future studies utilizing similar head impact sensors.

In video analysis, we found that by type of hit, those that occurred in players that were tackling another player with head-to-head contact generated the highest linear acceleration values at 56.1*g*. By field location of impact, we found that head-to-head impacts that occurred in the open field produced the highest linear acceleration values at 55.3*g*. Finally, by position of player, we found that skilled players involved in head-to-head impacts generated the highest linear acceleration values at 50*g*. Unfortunately our subgroup analyses did not have enough data points to generate statistical significance. While larger studies are necessary to confirm these results, awareness of the circumstances that generate the highest impact accelerations may allow for more directed rule changes in the future.

There are several limitations to the current study. First, there is finite data supporting the use of non-accelerometer based sensors. Most studies investigating head impacts use typical accelerometer-based sensors. These sensors, however, each cost approximately $1000, which may be economically prohibitive for widespread use especially at the youth or high school football levels. The sensor for the present study represents a relatively low cost alternative (approximately $150 per helmet) to monitor player hit counts over a season. Another important limitation is the inherent sensor threshold of 30*g* linear acceleration. This substantially reduces our absolute hit counts as well as skews our mean values higher when compared to previously published studies. The sensor also does not measure rotational acceleration. Finally, while we found statistically significant differences in hits per player during games versus practice, our subgroup analyses of player positions, field location of impact, type of hit, and presence of head-to-head impact did not yield any statistically significant results. Unfortunately, the current study was underpowered to assess those relationships.

However, despite these limitations, this study represents a unique data collection from an entire youth football team, and allows a greater appreciation of the number, type, and degree of head impacts. It shows not only that logistical and technical challenges can be overcome, but also that meaningful data can be obtained and perhaps, in the near future, allow us to determine the degree of head impact exposure. This data may provide useful knowledge concerning the weekly, season, or career exposure to head impacts, thus enabling more informed player management decisions. Our results also support previously published data suggesting that rule changes can be an effective way of reducing the number of cranial impacts and further nuances to those changes may allow us to mitigate the chronic, long-term risks of multiple head impacts.

References

[1] Iverson GL, Gaetz M, Lovell MR, Collins MW. Cumulative effects of concussion in amateur athletes. Brain Inj 2004;18:433–43.
[2] Guskiewicz KM, McCrea M, Marshall SW, Cantu RC, Randolph C, Barr W, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. JAMA 2003;290:2549–55.
[3] Parkinson D. Cumulative effects of concussion in high school athletes. Neurosurgery 2003;53:247, author reply 247–8.
[4] Collins MW, Lovell MR, Iverson GL, Cantu RC, Maroon JC, Field M. Cumulative effects of concussion in high school athletes. Neurosurgery 2002;51:1175–9, discussion 1180–1.
[5] Gaetz M, Goodman D, Weinberg H. Electrophysiological evidence for the cumulative effects of concussion. Brain Inj 2000;14:1077–88.
[6] Omalu BI, DeKosky ST, Minster RL, Kamboh MI, Hamilton RL, Wecht CH. Chronic traumatic encephalopathy in a National Football League player. Neurosurgery 2005;57:128–34, discussion 128–34.
[7] Omalu BI, DeKosky ST, Hamilton RL, Minster RL, Kamboh MI, Shakir AM, et al. Chronic traumatic encephalopathy in a national football league player: Part II. Neurosurgery 2006;59:1086–92, discussion 1092–3.
[8] Omalu B, Bailes J, Hamilton RL, Kamboh MI, Hammers J, Case M, et al. Emerging histomorphologic phenotypes of chronic traumatic encephalopathy in American athletes. Neurosurgery 2011;69:173–83, discussion 183.
[9] McKee AC, Cantu RC, Nowinski CJ, Hedley-Whyte ET, Gavett BE, Budson AE, et al. Chronic traumatic encephalopathy in athletes: progressive tauopathy after repetitive head injury. J Neuropathol Exp Neurol 2009;68:709–35.
[10] McKee AC, Stein TD, Nowinski CJ, Stern RA, Daneshvar DH, Alvarez VE, et al. The spectrum of disease in chronic traumatic encephalopathy. Brain 2013;136:43–64.
[11] Broglio SP, Eckner JT, Martini D, Sosnoff JJ, Kutcher JS, Randolph C. Cumulative head impact burden in high school football. J Neurotrauma 2013;28:2069–78.
[12] Crisco JJ, Wilcox BJ, Beckwith JG, Chu JJ, Duhaime AC, Rowson S, et al. Head impact exposure in collegiate football players. J Biomech 2013;44:2673–8.
[13] Casson IR, Pellman EJ, Viano DC. National football league experiences with return to play after concussion. Arch Neurol 2009;66:419–20.
[14] Casson IR, Pellman EJ, Viano DC. Concussion in the National Football League: an overview for neurologists. Phys Med Rehabil Clin N Am 2009;20:195–214, x.
[15] Casson IR, Viano DC, Powell JW, Pellman EJ. Twelve years of national football league concussion data. Sports Health 2013;2:471–83.
[16] Pellman EJ. Background on the National Football League's research on concussion in professional football. Neurosurgery 2003;53:797–8.
[17] Pellman EJ, Viano DC. Concussion in professional football: summary of the research conducted by the National Football League's Committee on Mild Traumatic Brain Injury. Neurosurg Focus 2006;21:E12.
[18] Daniel RW, Rowson S, Duma SM. Head impact exposure in youth football. Ann Biomed Eng 2013;40:976–81.
[19] Cobb BR, Urban JE, Davenport EM, Rowson S, Duma SM, Maldjian JA, et al. Head impact exposure in youth football: elementary school ages 9–12 years and the effect of practice structure. Ann Biomed Eng 2013. PMID: 23881111 [Epub ahead of print].
[20] Foreman S. A comparative analysis for the measurement of head accelerations in ice hockey helmets using non-accelerometer based systems. In: ASTM symposium on the mechanism of concussion in sports. 2013.
[21] Dashnaw ML, Petraglia AL, Bailes JE. An overview of the basic science of concussion and subconcussion: where we are and where we are going. Neurosurg Focus 2012;33. E5: 1–9.
[22] Guskiewicz KM, Marshall SW, Bailes J, McCrea M, Cantu RC, Randolph C, et al. Association between recurrent concussion and late-life cognitive impairment in retired professional football players. Neurosurgery 2005;57:719–26, discussion 719–26.
[23] Guskiewicz KM, Marshall SW, Bailes J, McCrea M, Harding Jr HP, Matthews A, et al. Recurrent concussion and risk of depression in retired professional football players. Med Sci Sports Exerc 2007;39:903–9.
[24] Rule Changes Regarding Practice & Concussion Prevention; 2012.