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Subconcussive Head Impact Biomechanics: Comparing Differing Offensive Schemes

Douglas Martini, MS, James Eckner, MD, MS, Jeffrey Kutcher, MD, and Steven Broglio, PhD, ATC

Abstract

Recent literature suggests that sub-concussive impacts may influence cognitive functioning across the lifespan. These effects are suggested to manifest as functional and possibly structural changes. Head impact biomechanics during American football have been characterized from the high school to professional level, but style of play has not been considered.

Purpose—The aim of this investigation was to quantify and compare head impact frequencies and magnitudes between two different offensive schemes.

Methods—We investigated the frequencies and magnitudes (linear acceleration [g], rotational acceleration [rad/s²], and HITsp) of head impacts sustained by 83 high school football athletes, playing for schools employing two different offensive schemes. The two schemes comprised of a run first offense (42 athletes) and a pass first offense (41 athletes). The Head Impact Telemetry System was used to record head impact measures.

Results—A total of 35,620 impacts were recorded across two seasons. Athletes in the run first offense sustained an average of 456 head impacts per season (41 practices and 9 games) while the pass first offense athletes sustained an average of 304 head impacts per season (44 practices and 9 games). The pass first offense however sustained significantly higher impact magnitudes ($p < 0.05$; 28.56g, 1777.58rad/s², and 16.24) than the run first offense (25.67g, 1675.36rad/s², and 15.48) across a season.

Conclusion—These data provide a first look at how different offensive strategies may influence head impact exposure in football athletes. In the study population, a run first offense was associated with more frequent head impacts, of smaller magnitude, than a pass first offense.

Introduction

Researchers have increasingly investigated and reported on head impact biomechanics in American football. Many of these investigations have focused on concussion mechanics and the association between impact magnitude, concussion risk, and post-injury outcomes (7, 15, 19, 20). More recently, there has been an increased interest in the role sub-concussive impacts may play in an athlete's cognitive health. In part, this interest spawns from recent reports suggesting that non-concussive blows occurring during football participation may lead to subclinical cognitive decline (1, 3, 8, 26). For example, imaging studies of football and hockey athletes indicate significant changes in white matter tracts and cerebral function in the limbic lobe and subcortical region (1, 3, 26). These changes occurred in absence of concussion symptoms or clinically measurable cognitive impairment and were associated with the number of head impacts sustained (3, 26). Bazarian et al. (1) similarly showed significant changes between controls and a multiple sub-concussive impact group of high school football and hockey athletes. Participants underwent diffusion tensor imaging (DTI) pre- and post-season (1) and the sub-concussive impact group demonstrated greater anisotropic and diffusional changes in white matter voxels than the controls (1). While the clinical significance of these changes is still not fully understood, some have suggested that

repetitive sub-concussive head trauma may lead to Chronic Traumatic Encephalopathy (CTE) (3, 26). In fact, post-mortem histopathological changes consistent with early CTE have been reported in contact sport athletes with no history of clinically diagnosed concussion (21).

While much of the current head impact biomechanics literature has focused on the collegiate athlete (9, 10,12, 17,22), high school athletes represent the single largest cohort of American football players annually. Approximately 1.2 million high school athletes participate in football annually, compared to only 68,000 athletes at the collegiate level. While the literature indicates that collegiate football players sustain higher impact frequencies and magnitudes than high school athletes (15,25), high school football players have been reported to sustain an average of 652 impacts in the regular season, with some athletes exceeding 2200 head impacts (7). Among high school athletes, the differences in impact frequency are based on a number of variables, including session type and playing position. Expectedly, a greater number of impacts occur during games (24.5) than practices (9.2) (4); and within game sessions, linemen sustained the most impacts (29), followed by quarterbacks (26); the tight end, running back, and linebacker group (24); and finally the receiver, cornerback, and safety group (16) (7). Similarly, linemen sustained the highest average number of annual impacts(868), followed by the tight end, running back, and linebacker group (619); quarterbacks (467); and finally the receiver, cornerback, and safety group (372) (7).

Similar position and session differences have been reported for impact magnitude, reported as linear(g) and rotational (rad/s²) accelerations. The Head Impact Telemetry severity profile (HITsp), a principal component calculation derived from linear acceleration, rotational acceleration, impact location, Gadd severity index (GSI), and head injury criterion (HIC) (15), has also been reported. Broglio et al. (5) found game sessions presented higher average impact magnitudes (26.1g and 1711.2 rad/s²) than practices (24.2g, 1554.3 rad/s²) for all players. On average, skill position players (i.e., running backs, receivers, cornerbacks, etc.) sustained higher impact magnitudes than linemen during game sessions (Broglio et al., 2011). Within the skill position group, a subset including tight ends, running backs, and linebackers sustained the highest overall post-impact rotational accelerations and HITsp (1789rad/s², 16.2); followed by quarterbacks (1787rad/s², 15.9); and the receiver, cornerback, and safety group (1771rad/s², 14.4)(Broglio et al., 2011). Linemen did sustain the lowest average rotational acceleration, however their HITsp was slightly higher than the receiver, cornerback and safety group (1659rad/s², 14.7) (7). Quarterbacks sustained the highest average linear accelerations (28.6g) during game sessions, followed by the tight end, running back, and linebacker group (27.1g); the receiver, cornerback, and safety group (26.6g); and finally, linemen (25.1g) (7). Collectively, the current literature suggests that offensive and defensive linemen sustain a higher number of impacts than other positions, but these impacts occur at lower magnitudes.

Although there have been considerable advances in our understanding of sub-concussive head impact frequencies and magnitudes, little is known about how style of play may influence these variables. While there is now sufficient evidence that shows differences in impact frequency and magnitude between skill players and linemen, it is unknown whether a team's overall offensive style influences these variables. That is, do teams favoring a pass versus run offense experience different head impact profiles? Therefore, the purpose of this investigation was to compare the head impact profiles of two high school football teams with differing offensive schemes. We tested the hypotheses that the frequency and magnitude of head impacts experienced by players at each school, position, and session differs between the two programs.

Methods

As part of an on-going investigation of concussion biomechanics in high school football, varsity level football players were recruited from two separate institutions. Participants included 42 Illinois Class 3A athletes and 41 Michigan Class A athletes. Athletes from the Illinois high school were enrolled during the 2009 season, while athletes from the Michigan high school were enrolled during the 2011 season. Prior to enrollment, all athletes completed an institutional review board approved informed assent document and informed consent was provided by parents/guardians prior to data collection.

Participating athletes were issued a Riddell (Elyria, OH) Revolution (Illinois) or Revolution Speed (Michigan) helmet prior to their season. Each helmet was retrofitted with a HITS encoder allowing biomechanical impact measures (e.g., linear acceleration, rotational acceleration, and HITsp) to be recorded. The HITS encoder includes six single-axis accelerometers, a wireless telemetry unit, a battery, and an onboard storage unit. The telemetry unit transmits data to a sideline computer via radio frequency. For an impact to be recorded, the post-impact acceleration must exceed a 15g threshold in a single accelerometer. Helmets instrumented with the HIT System have been approved by the National Operating Committee on the Standards for Athletic Equipment (NOCSAE). The HIT System has been utilized at various levels of competition, for multiple sports (2, 6, 9, 10, 12,22) to record head impacts. A more complete description is reported in previous literature (15). Data collection began at each team's first preseason practice and ended following the last regular season game. Data were monitored on a daily basis by one of the investigators for errant impacts (e.g., dropped helmet) which were marked and later removed from the dataset.

Data Analysis

Descriptive statistics were calculated for the number and magnitude of impacts (i.e., linear acceleration, rotational acceleration, and HITsp) based on offensive scheme (run or pass oriented), session type (game versus practice), and player position (quarterbacks, tight ends, running backs, wide receivers, offensive and defensive linemen, linebackers, cornerbacks, and safeties). The values for linear and rotational accelerations were natural log transformed before significance testing to maintain normality. Independent samples T-tests were used to analyze contrasts by position, by scheme, and by session type. Effect size (Cohen's d) was calculated to remove the effect of the sample size. A Cohen's d greater than .3 is considered moderately strong effect size, while above .6 is considered a strong effect size. The statistical program SPSS version 19 (SPSS, Chicago, IL) was used throughout and significance was noted when $p < 0.05$.

Results

A total of 35,681 head impacts were recorded from 83 athletes across the two high school football programs. A total of 63 impacts were removed from the dataset because they were deemed errant ($n=57$) or resulted in a physician diagnosed concussion ($n=6$). The six concussive impacts were removed to maintain focus on the sub-concussive impacts sustained over a season. As previously mentioned, recent literature has shifted in an attempt to quantify the possible cumulative effects of sub-concussive impact (1, 3, 8, 26). This resulted in the analysis of 35,618 impacts. The 2009 season (22,091 impacts; 41 practices, 9 games) data represents the regular season for the run-first-offense (RFO), while the 2011 season (13,527 impacts; 44 practices, 9 games) data represents the regular season for the pass-first-offense (PFO). Table 1 presents team statistics comparing the two offensive schemes. We categorized the two schools based on the coach's philosophy of play calling. The RFO coach established his offense through the run game, while the PFO coach

established his offense through the passing game. Athletes representing the RFO school (n=42: offense = 16; defense = 26) consisted of two quarterbacks, one tight end, three running backs, four wide receivers, six offensive linemen, twelve defensive linemen, five linebackers, five cornerbacks, and four safeties and were: 16.2 ± 0.6 yrs; 180.9 ± 7.2 cm; and 89.8 ± 20.1 kg at the time of enrollment. Athletes representing the PFO school (n=41: offense = 19; defense = 24) consisted of one quarterback, one tight end, four running backs, four wide receivers, nine offensive linemen, four defensive linemen, nine linebackers, eight cornerbacks, and one safety and were: 16.5 ± 0.8 yrs; 181.1 ± 9.5 cm; and 85.1 ± 19.6 kg at the time of enrollment. T-tests indicated no significant differences in participant demographics between the two schools (p 's > .05). To retain consistency with current literature, the impact counts and magnitudes for defensive players were also included in this analysis. These statistics are relevant both in accounting for impacts sustained by "two-way" players, and because many of the impacts sustained by defensive players occur during practice sessions when these players are lined up against their own team's offense.

We first evaluated difference in head impact frequencies between the two schools. Our analyses indicated significant impact differences for session type, offensive scheme, and player position (Table 2). Collectively, the average number of head impacts sustained per player during games was greater than during practices (19.02 ± 19.13 vs. 6.15 ± 4.52 , respectively; $t = 5.96$, $p < .05$). This finding was also observed when schools were evaluated individually (RFO practices: 8.10 ± 4.83 , games: 21.65 ± 18.53 ; $t = -4.59$, $p < .05$ and PFO practices: 4.16 ± 3.15 , games: 16.33 ± 19.60 ; $t = -3.93$, $p < .05$). When session type was combined, players at the RFO school sustained significantly more head impacts over the entire season than players at the PFO school, (455.8 ± 192.6 vs. 303.7 ± 148.0 , respectively; $t = 2.2$, $p < .05$). When session type was evaluated individually, there was a significant difference in the average number of head impacts during practice sessions between the RFO (8.10 ± 4.83) and PFO (4.16 ± 3.15 ; $t = 4.42$, $p < .05$) schools. However, head impact frequency during games did not differ between the RFO and PFO schools ($p > .05$).

We also evaluated the post-impact linear acceleration (g) of the head (Table 3). When evaluating all sessions, the PFO athletes sustained greater average linear accelerations across the season than the RFO athletes (28.56 ± 17.84 g vs. 25.67 ± 15.30 ; $t = -16.08$, $p < .05$). Among the player positions, the seasonal linear acceleration values were significantly different at the running back ($t = -3.69$, $p < .05$), wide receiver ($t = -3.61$, $p < .05$), offensive linemen ($t = -10.24$, $p < .05$), defensive linemen ($t = -7.31$, $p < .05$), and linebacker ($t = -7.93$, $p < .05$) positions. As expected, post-impact linear accelerations for both schools were greater during games than practice sessions (27.67 ± 17.36 g vs. 26.18 ± 15.67 , $t = -7.49$, $p < .05$). The average linear acceleration also differed significantly between the RFO and PFO schools during practice sessions (25.18 ± 14.52 vs. 28.07 ± 17.47 , respectively; $t = -12.29$, $p < .05$), as well as during games (26.55 ± 16.55 vs. 29.17 ± 18.28 , respectively; $t = -9.49$, $p < .05$). Further analyses of the practice sessions indicated significant differences between schools for the running backs ($t = -3.20$, $p < .05$), wide receivers ($t = -3.56$, $p < .05$), offensive linemen ($t = -8.79$, $p < .05$), and defensive linemen ($t = -3.31$, $p < .05$), and linebackers ($t = -6.89$, $p < .05$). Significant differences were also found between schools during game sessions at the tight end ($t = -3.91$, $p < .05$), offensive linemen ($t = -4.81$, $p < .05$), defensive linemen ($t = -6.34$, $p < .05$), linebackers ($t = -4.33$, $p < .05$), and safety ($t = 2.64$, $p < .05$) positions.

The evaluation of rotational accelerations (rad/sec²) (Table 4) yielded similar findings as the linear acceleration data. Overall, when evaluating all session types, the PFO athletes sustaining greater seasonal average rotational accelerations than RFO athletes (1777.58 ± 1266.61 vs. 1675.36 ± 1183.94 ; $t = -8.38$, $p < .05$). However, only the defensive linemen ($t = -5.87$, $p < .05$), linebackers ($t = -3.77$, $p < .05$), and cornerbacks ($t = -3.86$, $p < .05$) positions.

05) differed significantly across the season. When the athletes from both schools were evaluated, game sessions (1791.24 ± 1306.45) again resulted in higher post-impact rotational accelerations than practice sessions (1664.24 ± 1152.61 , $t = -6.31$, $p < .05$). Practice sessions were associated with significant group differences between the RFO and PFO athletes for average rotational accelerations (1637.29 ± 1119.60 vs. 1714.73 ± 1287.14 ; $t = -4.86$, $p < .05$). Significant differences were noted at the tight end ($t = 1.99$, $p < .05$), defense linemen ($t = -2.97$, $p < .05$), linebackers ($t = -3.15$, $p < .05$), cornerbacks ($t = -3.39$, $p < .05$), and safeties ($t = -2.22$, $p < .05$). Greater average rotational accelerations were also associated with game sessions between the PFO and RFO athletes (1855.82 ± 1328.94 vs. 1742.48 ± 1287.14 rad/sec²; $t = -6.42$, $p < .05$); with significant differences were recorded among the quarterback ($t = -2.30$, $p < .05$), tight end ($t = -2.78$, $p < .05$), defensive linemen ($t = -4.79$, $p < .05$) linebacker ($t = -2.19$, $p < .05$), and cornerback ($t = -1.99$, $p < .05$) positions.

Lastly, we evaluated difference in HITsp between the two teams (Table 5). Across all sessions in the season, the PFO athletes (16.24 ± 9.29) sustained higher average HITsp values than their RFO counterparts (15.48 ± 7.94 ; $t = -7.90$, $p < .05$); with seasonal difference noted among the running backs ($t = -2.59$, $p < .05$), wide receivers ($t = -2.95$, $p < .05$), defensive linemen ($t = -5.16$, $p < .05$), linebackers ($t = -5.18$, $p < .05$), and cornerbacks ($t = -2.04$, $p < .05$). When the athletes from both schools were evaluated, game sessions (16.41 ± 9.30) resulted in higher post-impact HITsp values than practice sessions (15.36 ± 7.90 , $t = -11.05$, $p < .05$). When only practice sessions were evaluated, the PFO athletes (15.68 ± 8.72) sustained a greater average HITsp than the RFO athletes (15.19 ± 7.41 ; $t = -4.17$, $p < .05$); with difference noted among the tight ends ($t = 2.33$, $p < .05$), wide receivers ($t = -2.13$, $p < .05$), defensive linemen ($t = -2.13$, $p < .05$), linebackers ($t = -4.17$, $p < .05$), and cornerbacks ($t = -1.97$, $p < .05$). Differences between schools were also found for game sessions with a significant group differences between PFO athletes (16.94 ± 9.91) and their RFO counterparts (16.01 ± 8.78 ; $t = -5.80$, $p < .05$). The finding was driven by differences among the tight ends ($t = -4.27$, $p < .05$), defensive linemen ($t = -4.36$, $p < .05$) and linebackers ($t = -3.33$, $p < .05$) sustained significantly different average HITsp values during game sessions.

Discussion

The purpose of this investigation was to compare the biomechanical properties of head impacts between two high school football programs employing different offensive schemes. While previous investigations have described the biomechanical properties of head impacts, none have accounted for differences in offensive schemes. Most notably, when comparing head impact frequency across all players and sessions in a season, the RFO athletes sustained 1.5 times more head impacts than the PFO athletes (455.8 vs. 303.7, respectively). The head impact counts observed in this study are consistent with recent literature reporting similar average numbers of head impacts across a season in high school football players. Schnebel et al. (25) reported an average of 520.4 head impacts, while others have reported 652 and 549.3 head impacts across a season (4,7, respectively). These counts pale in comparison to the average number of head impacts sustained by collegiate football athletes (1353.9) across a season (25). The difference between high school and collegiate impact counts is likely due to the discrepancy in the number of practices and games between the high school (39.2 practices and 11.5 games) and college (93 practices and 12 games) levels (4, 7, 25).

The observed difference in head impact frequency between schools resulted primarily from differential impact frequencies during practice. The RFO athletes sustained nearly double the number of head impacts during practices (8.1) as compared to the PFO athletes (4.1). Compared to their practice averages, the RFO athletes sustained nearly three times more impacts during game session (21.6), while the PFO athletes sustained just under four times

more impacts during game sessions (16.3). This difference in game impact frequency between schools was not statistically significant, though practice impact frequencies were significantly different between schools. These findings are similar to previous reports, which have also demonstrated higher head impact averages during game sessions (23.5 – 24.5) as compared to during practices (6.4 – 9.2) (4, 7, respectively). However, the difference noted during practice sessions was not equal across all playing positions. The largest discrepancy between schools occurred at the defensive line position. The RFO defensive linemen sustained more than double the number of head impacts per practice session than the PFO defensive linemen. Similarly, the RFO cornerbacks sustained nearly double the amount of head impacts per practice session than their PFO counterparts. Though not statistically significant, the RFO quarterbacks, tight end, running backs, wide receivers, offensive linemen, defensive linemen, linebackers, cornerbacks, and safeties sustained greater average head impact frequencies than the equivalent PFO positions for game sessions. While these data support our theory that head impact exposure may be influenced by a football team's offensive scheme for these two schools, potential effects of additional unmeasured confounding variables may be present. We cannot exclude the possibility that differences in coaching philosophies for practice session drills may alternatively account for some of the observed differences.

While RFO athletes sustained greater head impact frequencies, higher average head impact magnitudes were recorded in PFO athletes. Collectively, significantly greater impact magnitudes occurred during game sessions than practice sessions. This finding is also consistent with previous reports (4, 7) showing greater impact magnitudes during game sessions than practice sessions at the high school level (24.8g and 1669.8rad/sec² for games and 23.3g and 1468.6rad/sec² for practices). Finally, a larger seasonal average HITsp value was observed in the PFO athletes, as compared to the RFO athletes. Interestingly, PFO wide receivers and running backs sustained significantly greater HITsp values across a season than their RFO counterparts. This suggests that head impact magnitudes may be greater in athletes whose teams employ offensive schemes that focus on passing, as seen in this population. Though, similar to the impact counts data, more seasonal data is needed before these findings can be broadly generalized. Additionally, though the impact magnitudes are significantly different between the two schools, there may not be a strong clinical meaning. Until the effects of an athlete's cumulative head impact burden are better understood, these small differences in impact magnitudes will be difficult to interpret.

The differences in impact magnitudes between RFO and PFO schools may be partially attributed to the larger number of pass attempts (Table 1) at the PFO school. Indeed, in a pass first offensive scheme, the athletes are spread across more of the playing field than they are in a run first offensive scheme. The PFO athletes, particularly the wide receivers, running backs, and tight ends may be able to reach higher running velocities before contacting an opponent than the equivalent RFO athletes. That is, larger distances between athletes in a passing offense may lead to greater initial velocities prior to impact [$\text{acceleration} = (\text{velocity}_{\text{final}} - \text{velocity}_{\text{initial}})/\text{time}$]. As such, the PFO athletes would have larger initial velocities that resulted in greater deceleration values following impact. In fact, the linear accelerations and HITsp values recorded in PFO running backs and wide receivers over the whole season were significantly greater than those recorded in the RFO running backs and wide receivers. Though not significant, a similar trend was observed for rotational accelerations at these positions.

In comparison to other works evaluating impact magnitudes, the median HITsp value for collegiate football athletes has been reported at 13.8 (11) and Bantam ice hockey athletes have been reported to sustain a HITsp value of 15.8 (23). The discrepancy between the younger and older athletes' magnitudes has been attributed to weaker neck muscles among

the less developed athlete (4). When simulations of older, more mature athletes were evaluated, higher neck stiffness was shown to decrease post-impact head acceleration in the “struck” professional player (27). However, an in vivo investigation found there to be no significant differences between athletes’ static neck strengths and response to perturbation (24). It should be noted that the Mihalik et al. (24) findings were collected from young (mean age = 15.1yrs) hockey players, while Viano et al. (27) reviewed professional football (NFL) video and reproduced using Hybrid III dummies to calculate magnitudes and neck strengths.

Preceding these findings, our laboratory characterized the cumulative impact burden sustained by high school football players (7). Across four seasons (652 head impacts/season), the average linear acceleration was 26.2g and the average rotational acceleration was 1692.0rad/sec² (7). These average magnitudes are lower than those observed in the PFO school. While our current data indicate that the PFO athletes sustained fewer head impacts overall, the magnitude of these impacts appears to be greater. When compared to head impact magnitudes recorded in collegiate football players and high school-aged hockey athletes, the discrepancy in average magnitudes becomes more striking for the PFO athletes. Indeed, Crisco et al. (11) reports a median linear acceleration of 20.5g and a median rotational acceleration of 1400rad/sec² across three seasons (304 head impacts/season) of Division I football. Furthermore, bantam-level ice hockey players (mean age = 14yrs) were shown to sustain an average 21.5g linear and 1441.1rad/sec² rotational accelerations per head impact (288 head impacts/season) (23). What this means to both the risk for concussion and long term cognitive health among PFO athletes cannot be discerned from this investigation. Previous investigations have suggested that an accumulation of sub-concussive impacts could lead to chronic diseases such as depression, mild cognitive impairment, and/or chronic traumatic encephalopathy (CTE) later in life (13, 18, 19). More recently, investigators utilizing imaging techniques have correlated multiple sub-concussive impacts and sub-clinical cognitive declines in high school athletes (1, 3, 26). The relative contributions of impact frequency and magnitude to these potential adverse neurocognitive outcomes remain undefined.

This study has several limitations that should be addressed. One limitation is the use of linear acceleration, rotation acceleration, and HITsp to quantify head impact magnitudes. While previous investigations have suggested that repetitive head impacts could be linked to deleterious, pathological effects on the brain (1, 3, 14, 21, 26), there has been no investigation that has directly associated these two phenomena or the role that impact magnitudes play. To remain consistent with the current concussion biomechanics literature, we felt it appropriate to quantify and compare head impact magnitudes between the two teams reporting linear acceleration, rotational acceleration, and HITsp as our impact magnitude variables. An additional limitation is that the two schools used two different helmets (Riddell Revolution [RFO] and Revolution Speed [PFO]) during the study. As the HIT System records post-impact head accelerations, the helmet type would likely not have affected these measurements. In addition, players were categorized based on their primary position, but in those athletes who played more than one position or who played “both ways,” we were unable to separate head impacts experienced at each of their positions. Furthermore, we did not record the number of plays each athlete participated in during each practice or game session. We also could not control play calls or changes in play call strategy in response to the direction of a game, nor could we control the practice conditions which often fluctuated in response to the team’s performance during the previous session(s). Lastly, we were unable to quantify or control for the defensive schemes the participating teams faced or for potential skill level discrepancies between them or their competitors. Future work should address these limitations and investigate a larger number of RFO and PFO

teams before final conclusions about the effect of offensive scheme on head impact exposure can be drawn.

The relationship between the frequency and magnitude of head impacts experienced by an athlete and their long term neurocognitive health is not well understood. Some have recently suggested the application of “impact counts” to limit the impact burden sustained by an athlete (16). This recommendation is intuitive and well intentioned, but currently lacks supportive evidence. Within our population, the findings suggest that those participating in a spread offensive scheme (PFO) sustain fewer impacts at a greater magnitude than those participating in a run based offensive scheme (RFO). The significance of this apparent frequency vs. magnitude trade-off with respect to long term health outcomes remains to be defined, but absolute impact counts will likely not quantify brain injury risk. Once these complex relationships are clarified, then offensive scheme and play selection may become a viable method for risk reduction in American football. As a first look at contrasting offensive philosophies, we intend to expound on what was found in a more empirical format in future investigations.

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Table 1

	Game Performance Based on 9 Regular Season Games				
	Pass Attempts	Pass Completion	Pass Yards	Run Attempts	Run Yards
PFO School	25.6	14.6 (57%)	270.6	26.3	107.2
RFO School	8.8	6.6 (75%)	97.1	32.9	282.9

Offensive statistics for the PFO and RFO schools

Table 2

	Practice		Game		Season	
	RFO School*	PFO School	RFO School	PFO School	RFO School*	PFO School
QB	1.79±1.05	0.98	13.50±17.99	9.22	195.00±205.06	126
TE	10.66	5.98	4.89	25.56	481	493
RB	8.21±2.98	2.25±1.03	26.48±9.31	11.03±11.13	575.00±73.91**	198.25±133.88
WR	4.99±2.21	2.23±1.38	14.03±12.13	11.44±7.67	330.75±199.77	201.25±126.56
OL	10.84±2.85**	6.75±3.68	24.48±14.14	24.04±30.71	664.83±224.44	513.22±402.85
DL	11.84±5.49**	4.93±3.23	28.36±27.49	26.00±26.64	740.83±426.96	450.75±380.32
LB	7.21±2.93	4.42±3.82	28.60±15.86	16.14±17.71	553±259.01	339.67±314.27
CB	4.68±1.96**	2.94±1.00	14.18±8.38	8.17±10.94	319.40±147.16	202.88±137.32
S	3.69±2.70	1.86	10.17±7.75	14.00	242.75±177.71	208

Average Number of Head Impacts: mean±sd,

* indicates $p < .05$ between schools,

** indicates $p < .05$ between positions

Table 3

	Practice		Game		Season	
	RFO School*	PFO School	RFO School*	PFO School	RFO School*	PFO School
QB	24.51±14.90	21.23±12.32	27.03±15.75	28.51±18.13	26.07±15.46	26.03±16.69
TE	28.86±15.77	29.08±17.21	22.49±11.16**	31.97±19.64	28.30±15.51	30.43±18.42
RB	25.80±15.31**	29.46±20.67	28.74±19.64	31.95±22.91	26.94±17.17**	30.71±21.84
WR	24.06±15.02**	27.21±17.22	25.78±16.81	27.12±17.66	24.71±15.74**	27.16±17.44
OL	24.57±13.25**	27.97±15.93	26.64±16.34**	28.83±16.91	25.26±14.38**	28.33±16.36
DL	25.25±14.64**	27.54±17.68	25.81±15.33**	29.77±18.54	25.43±14.87**	28.76±18.22
LB	24.75±13.44**	28.89±18.63	26.51±15.96**	29.64±19.05	25.54±14.65**	29.21±18.81
CB	26.10±15.88	27.15±17.95	26.48±17.41	27.76±17.21	26.25±16.51	27.37±17.68
S	24.92±15.74	27.33±16.51	30.49±21.78	24.98±14.04	26.76±18.14	25.91±15.07

Average Linear Acceleration (g): mean±sd,

* indicates $p < .05$ between schools,

** indicates $p < .05$ between positions

Table 4

	Practice		Game		Season	
	RFO School*	PFO School	RFO School*	PFO School	RFO School*	PFO School
QB	1378.68±1137.25	1177.56±1082.50	1531.00±1217.61**	1912.59±1588.17	1473.44±1188.71	1661.75±1473.45
TE	2035.85±1390.69**	1808.26±1341.81	1369.04±919.79**	2120.65±1657.79	1974.85±1367.31	1954.00±1504.09
RB	1698.42±1136.15	1859.49±1438.76	1838.45±1266.84	2028.67±1561.34	1752.59±1189.99	1944.19±1502.82
WR	1565.59±1171.08	1698.03±1272.04	1746.59±1239.63	1867.81±1399.29	1634.68±1200.47	1784.93±1340.54
OL	1618.90±1027.36	1596.96±1029.95	1825.56±1368.61	1757.36±1114.51	1687.39±1155.64	1664.57±1069.23
DL	1642.16±1128.19**	1756.86±1243.51	1708.55±1255.58**	1962.78±1460.92	1664.02±1172.95**	1869.41±1367.74
LB	1588.26±984.13**	1795.63±1275.68	1717.21±1196.85**	1841.87±1345.18	1646.27±1086.69**	1815.40±1305.83
CB	1632.62±1143.00**	1786.57±1317.58	1734.79±1339.28**	1847.47±1313.91	1673.44±1225.81**	1808.63±1316.17
S	1591.98±1321.09**	1711.72±1148.99	1842.53±1633.22	1661.62±1207.03	1674.85±1435.82	1681.37±1181.94

Average Rotational Acceleration

(rad/s^2); mean±sd,

* indicates $p < .05$ between schools,

** indicates $p < .05$ between positions

Table 5

	Practice		Game		Season	
	RFO School*	PFO School	RFO School*	PFO School	RFO School*	PFO School
QB	13.16±8.00	12.47±4.50	14.40±7.08	16.65±11.76	13.93±7.45	15.23±10.08
TE	18.22±9.08**	16.71±7.80	14.61±5.92**	19.69±11.96	17.89±8.89	18.10±10.06
RB	15.32±7.64	16.44±12.26	16.53±9.77	17.65±12.48	15.79±8.55**	17.05±12.38
WR	14.28±6.90**	15.31±8.37	15.54±9.15	16.45±9.57	14.76±7.87**	15.89±9.02
OL	14.86±6.61	15.06±7.60	16.54±9.28	16.38±8.61	15.42±7.64	15.62±8.07
DL	15.41±7.73**	16.09±9.03	15.86±8.04**	17.45±10.23	15.56±7.83**	16.81±9.73
LB	15.04±6.46**	16.19±9.24	16.05±7.92**	17.27±10.69	15.49±7.17**	16.65±9.90
CB	14.97±7.86**	15.71±8.97	15.83±9.86	16.37±9.10	15.31±8.72**	15.95±9.02
S	14.53±7.43	16.27±8.16	16.51±12.47	15.58±6.26	15.19±9.44	15.85±7.06

Average HITsp: mean±sd,

* indicates $p < .05$ between schools,

** indicates $p < .05$ between positions