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Comparison of Impact Performance between Youth and Varsity Football Helmets

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Abstract

Current youth football helmets, intended for players under the age of 14 years old, are similar in design and are tested under the same standard as varsity football helmets. This study evaluated the impact performance of matched youth and adult varsity football helmets. Eight helmet models were evaluated using an impact pendulum, with a modified National Operating Committee on Standards for Athletic Equipment (NOCSAE) medium sized headform mounted on a Hybrid III 50th percentile neck. Four locations on the helmet shell at three impact velocities were tested for three trials, for a total of 576 impact tests. Linear acceleration, rotational acceleration, and a concussion correlate were recorded for each test and a comparison between the youth and varsity helmets were made. It was found that the age group the helmet is intended for did not have a significant effect on the impact performance of the helmet in either linear acceleration, rotational acceleration, or concussion correlate. These results are likely due to the similarities in helmet design resulting from being tested to the same standard. Although it is unknown how a youth helmet should differ from a varsity helmet, differences in impact exposure, anthropometry, physiology, and injury tolerance are factors to consider. These data serves as a reference point for future youth-specific helmet design and helmet standards.

INTRODUCTION

Football has a high incidence of concussion due to the physicality of the sport, and because of its popularity, accounts for a large proportion of sports-related concussions.¹ Ongoing research is looking at reducing concussion incidence in sports through a variety of inventions. These interventions can be divided into one of three categories: adjusting rules of the game, enforcing proper tackling techniques, or improving the design of helmets.^{2, 3} This study focuses on the improvement helmet of design by evaluating the relative performance of youth and varsity football helmets.

Youth football players, defined as those under the age of 14, make up approximately 70% of the participants in football nationwide.⁴ Youth players typically see fewer impacts per season than high school and collegiate players, mostly due to participation in fewer games and practices.^{2–7} The number of impacts a player experiences per season increases as they get older. Youth players will sustain between 148 and 213 head impacts per season, depending on their age group,^{2, 4, 5} whereas collegiate players will experience a median of 420 head impacts per season.⁶ All age groups sustain high severity impacts, but older players will experience high severity impacts more frequently.^{2, 5, 6, 8} From a rules

perspective, some youth leagues do not perform plays that pose a high risk of injury, such as kickoffs and punts.⁹

Youth helmets are intended for players under the age of 14, and varsity helmets are meant for players age 14 and older. Youth helmets are typically similar to their varsity counterparts in both design and liner materials. However, varsity helmet shells are typically composed of polycarbonate, whereas youth helmet shells are typically composed of acrylonitrile butadiene styrene (ABS). While both materials are used for their impact resistive properties, but ABS is cheaper, lighter, more compliant, and has a lower tensile strength. There are additional youth-specific helmets without varsity equivalents that are available for purchase which may present additional differences. Currently, all helmets, both youth and varsity, must pass the same set of impact performance criteria based on the standards from the National Operating Committee on Standards for Athletic Equipment (NOCSAE).¹⁰ A set of youth-specific standards has been put forth by NOCSAE for youth football helmets with additional tests and performance criteria.¹¹ We have previously related the NOCSAE standard test conditions to on-field head impact measurements and found that drop tests represent similar impacts for both age levels. Given that catastrophic head injuries have been eliminated from sports, our data suggest different standards would have little effect. Once more is known about youth concussion, standards likely will need to differentiate impact performance criteria for youth helmets.¹²

The objective of this study was to investigate differences in impact performance between matched youth and varsity football helmets. There are no data currently available relating the performance of youth and varsity helmets, with respect to linear and rotational head kinematics, both of which contribute to concussion risk.¹³ It is hypothesized that due to the similarity in the youth and varsity helmets that there will be no differences in their impact performance. These data have applications of improving helmet design and helmet standards, specifically in regards to the youth population.

METHODOLOGY

Helmet models that had a matched youth and varsity version at the time of the study were used. A total of 8 models fit this criterion: Riddell 360 (360), Schutt Air XP Pro (AXP), Schutt DNA Pro+ (DNA), Rawlings NRG Impulse (IMP), Riddell Speed (SPD), Riddell Speedflex (SPDF), Schutt Vengeance DCT (VEN), and Xenith X2E (X2E). One varsity and one youth helmet were purchased for each of these models.

An impact pendulum was used to evaluate the performance of each helmet.¹⁴ The pendulum arm was 190.5 cm long with a 16.3 kg impacting mass fitted with a flat nylon impactor face. The impactor struck a helmeted, medium sized NOCSAE headform (57.6 cm circumference) which had been modified to couple with a Hybrid III 50th percentile neck. The NOCSAE headform was selected as the headform shape provides a more realistic helmet fit compared to a Hybrid III headform.¹⁵ The modified NOCSAE head and neck assembly has been shown to produce a similar impact response to the Hybrid III.¹⁶ The head and neck assembly was mounted to a sliding mass on a commonly used linear slide table (Biokinetics, Ottawa, Ontario, Canada), where the sliding mass is intended to simulate the mass of the torso.¹⁷ The

headform was instrumented with 3 linear accelerometers (Endevco 7264B-2000, Meggitt Sensing Systems, Irvine, CA) and a triaxial angular rate sensor (ARS3 PRO-18K, DTS, Seal Beach, CA) at the center of gravity of the headform, which allowed linear and angular kinematic measurements with 6 degrees of freedom. All data were sampled at 20 kHz and filtered using a 4 pole phaseless Butterworth filter. Acceleration data were filtered using a cutoff frequency of 1650 Hz (CFC 1000) and angular rate data were filtered using a cutoff frequency of 255 Hz, which best matched rotation accelerations measured from a 9 accelerometer array.

Each helmet was tested at front, back, side, and top impact locations (Figure 1). These locations encompass a variety of shell impacts that could be experienced during play.^{2, 6, 18} Each impact location is based on translation from the zero point, defined by where the tip of the nose of the headform contacts the center of the pendulum, and rotation about the y and z axes (Table 1). The coordinate system used is defined by SAE J211. The x-translation is variable, measured where the pendulum just touches the helmet when hanging. For each impact location, impact velocities of 3.0, 4.6, and 6.1 m/s were tested. The impact velocities used are inclusive of the broad range of head acceleration magnitudes experienced by football players, including sub-concussive and concussive impacts.¹⁴ Furthermore, helmets were tested without a facemask. We have previously shown that the facemask does not make a significant difference in head acceleration for impacts to football helmet shells.¹⁹ Every impact scenario was repeated for 3 trials to yield a total of 576 tests. For each test, peak resultant linear acceleration, peak resultant rotational acceleration, and a concussion correlate value were computed.

Concussion correlate was used to describe overall impact severity and is calculated using both linear acceleration (a) and rotational acceleration (α) (Equation 1). This metric can give both positive and negative numbers, with increasing values being indicative of increased impact severity, and has been shown to be a good predictor for AIS 2+ brain injury compared to other metrics.²⁰ The concussion correlate is based on an analysis of on-field head acceleration data collected from football players consisting of injurious and non-injurious head impacts.¹³ Concussion correlate is used in place of the underlying risk function here due to potential differences in youth and adult injury tolerance.

$$CC = -10.2 + 0.0433 \cdot a + 0.000873 \cdot \alpha - 0.00000092 \cdot a \cdot \alpha \quad (1)$$

A three factor ANOVA with repeated measures was used to describe significant effects. Random effects were assumed for helmet model in the analysis. Differences were assessed using factors of age group, location, energy level, and all interaction terms. When necessary, Tukey HSD tests were used for post-hoc analysis. Statistical significance was set at $p < 0.05$ for all comparisons. Additionally, a linear regression model was fit to linear acceleration, rotational acceleration, and concussion correlate to characterize overall differences between youth and varsity helmets.

RESULTS

The 3.0 m/s impacts generated an average linear acceleration of 37.9 ± 10.7 g, average rotational acceleration of 2036 ± 448 rad/s², and average concussion correlate of -6.85 ± 0.64 . The 4.6 m/s impacts generated an average linear acceleration of 73.5 ± 15.0 g, average rotational acceleration of 3949 ± 924 rad/s², and average concussion correlate of -3.84 ± 1.10 . For the 6.1 m/s impacts, averages were 114.3 ± 22.5 g for linear acceleration, 6117 ± 1684 rad/s² for rotational acceleration, and -0.57 ± 1.83 for concussion correlate. Across all energy levels and locations, the youth helmets produced an average linear acceleration of 74.7 ± 35.3 g, average rotational acceleration of 3996 ± 2017 rad/s², and average concussion correlate of -3.81 ± 2.88 . These averages are comparable to the varsity helmets, where averages observed were 75.7 ± 35.7 g for linear acceleration, 4071 ± 2024 for rotational acceleration, and -3.71 ± 2.87 for concussion correlate.

The factor of helmet age group (youth vs. varsity) did not have a significant effect on linear acceleration ($p = 0.4768$), rotational acceleration ($p = 0.4714$), or concussion correlate ($p = 0.4351$). The differences between the youth and varsity helmets was insignificant across helmet models for linear acceleration, rotational acceleration, and concussion correlate (Figure 2). Matched differences were calculated by subtracting the average values for each impact configuration for the youth helmet from the matched varsity helmet values. Location had a significant effect on linear acceleration ($p = 0.0010$), rotational acceleration ($p = 0.0028$), and concussion correlate ($p = 0.0346$). The factor of energy level had a significant effect on all measurements ($p < 0.0001$). Additionally the interaction of location and energy level had a significant effect on linear acceleration ($p = 0.0015$), rotational acceleration ($p < 0.0001$), and concussion correlate ($p < 0.0001$). The interaction between factors of age group and location had no significant effects on linear acceleration ($p = 0.0910$) or concussion correlate ($p = 0.2848$). A significant effect was found for the age group and location interaction for rotational acceleration ($p = 0.0382$), however post hoc tests found no significant effects when matching locations between age groups. For the age group and energy level interaction no significant effect was found on linear acceleration ($p = 0.1709$), rotational acceleration ($p = 0.6516$), or concussion correlate ($p = 0.3011$).

The impact response for the youth and varsity helmets were highly correlated in linear acceleration, rotational acceleration, and concussion correlate. On average, linear acceleration for youth helmets were 98% that of varsity helmets ($R^2 = 0.9223$, $p < 0.0001$). Rotational acceleration, on average, for youth helmets was also 98% that of varsity helmets ($R^2 = 0.9235$, $p < 0.0001$). On average, concussion correlate for youth helmets was 101% of varsity helmets ($R^2 = 0.8961$, $p < 0.0001$) (Figure 3). For reference, a perfectly symmetrical data set would have a slope of 1, with an R^2 value of 1.

DISCUSSION

This study is the first to biomechanically compare the relative performance of matched youth and varsity football helmets. It was found that the youth and varsity helmets did not differ in impact performance. It should be noted however that youth and adult football

players differ in impact exposure, anthropometry, and brain physiology. These differences are likely associated with differences in concussion tolerance.²¹

Differences between youth and varsity helmets were likely not observed due to matched helmets being similar in design and youth and varsity helmets being tested to the same standard. Age group was found not to have any effect on the impact performance in any of the helmet models tested (Figure 2). Some helmets had more variance in their matched differences. This can likely be attributed to the different energy mitigation strategies that different helmets employ, some of which are susceptible to more variance than others.

The design characteristics of a youth helmet are similar to the helmets used in the adult game, where the difference between matched models is the material used for the helmet shell. For each of the helmets used here, the varsity version used polycarbonate for the shell material and the youth version utilized ABS, with the exception of the Rawlings NRG Impulse which used polycarbonate for both models. The use of ABS in place of polycarbonate produces a youth helmet that is about 5% lighter than its varsity counterpart for these helmets. In the Rawlings and Schutt models the varsity helmets used a 7/8" jaw pad where the youth helmets use a 1 1/8" jaw pad. The jaw padding, however, is not impacted in any of our impact locations and these pads are interchangeable with different size pads for comfort. Otherwise, the liner dimensions were identical between matched helmets. The similarity in design and being tested to the same standard youth and varsity helmets that do not perform differently.

The linear and rotational values reported in this study are indicative of the range of on-field acceleration values for both youth and adult football players, where both see a similar range of acceleration values.^{2, 4-6, 22} Additionally, these data include the range of accelerations in which concussions have been found to occur. For adult football players, numerous concussions have been recorded using helmet mounted accelerometer arrays, with the average injury occurring with average linear and rotational accelerations of 100 g and 5000 rad/s².^{13, 23, 24} Fewer concussions have been recorded in youth football, with injury measurements of 26 g and 1152 rad/s², 64 g and 2830 rad/s², 58 g and 4548 rad/s², and 95 g and 3148 rad/s².^{2, 8} Further work needs to be done to gain a better understanding of the biomechanics of concussion in youth football, which will further inform youth-specific helmet design.

Although it is unknown how a youth helmet should differ from a varsity helmet, some considerations offer insight to the challenges of designing youth-specific helmets. Head mass and size only differ slightly between youth and adult players, as the head is already about 95% fully grown around three and half years old. The head then fully matures to full adult size between the ages of 10 and 17.²⁵ A child's smaller body, however, means the head-to-body size ratio is much greater compared to a fully grown adult. Additionally, a child will have reduced strength and musculature in their neck and upper body.²⁶ There are concerns that youth players are more susceptible to concussion than adult players. It is still relatively unknown how concussion differs physiologically in the youth population, but some concerns include a developing nervous system, thinner cranial bones, differences in blood flow to the brain, and a larger subarachnoid space.^{26, 27} Biomechanically, youth

players may also have a lower concussion tolerance.²¹ However, due to the limited sample of concussions in youth players, the differences in injury tolerance are not fully understood. Although older players experience more impacts per season, it is important to note that younger players do still experience high magnitude head impacts, just at a lower frequency compared to older players.^{2, 3, 5}

This study was limited in several ways. First, performance differences of only matched youth and varsity helmets were investigated. Although no differences were found, it is unknown how the performance of helmets without youth or varsity counterparts may differ. Second, the test setup used here was specific to an average adult male and may not best represent the impact response of a youth player. These differences were not considered in the current study in order to make an effective comparison in helmet performance. Third, concussion correlate was calculated for both the youth and varsity helmets although this injury metric was developed using data from collegiate football players.¹³ This measurement is still useful as it provides a severity summary value that considers both linear and rotational acceleration. It is unknown how the injury tolerance of youth players differ from adult players, and no youth specific injury metrics have been developed.

CONCLUSION

To evaluate the relative biomechanical performance of youth and varsity football helmets, eight helmet models with matched youth and varsity versions were evaluated through a series of impact tests using a pendulum impactor. No differences were found between the youth and varsity helmets in these impact tests, likely due to the similarity in design between helmets and being tested to the same standard. It is currently unknown how youth and varsity helmets should differ. These data serve as a reference point for future youth-specific football helmet design and standards.

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Figure 1.
 (A) Front, (B) back, (C) side, and (D) top locations were tested at 3.0, 4.6, and 6.1 m/s impact velocities. Matched youth and varsity helmets were tested for three trails of each impact scenario without a facemask.

Figure 2.

Distribution of matched differences for (A) linear acceleration (B) rotational acceleration and (C) concussion correlate, where differences were calculated for matched trials by subtracting the youth measurement from the varsity measurement. The middle of the box represents the median, with the edges giving the 25th and 75th percentiles. Whiskers represent 1.5 times the interquartile range.

Figure 3.

Comparison for matched youth and varsity helmets for (A) linear acceleration, (B) rotational acceleration, and (C) concussion correlate. This indicates that performance was highly correlated for matched helmets in that all lines of best fit have slopes near 1 and have high R^2 values.

Table 1

Measurements for locations based on the zero point defined by the tip of the nose contacting the center of the pendulum. The coordinate system is as define by SAE J211. The left side is impacted for the side location, and the right side is impacted for the top location.

	Y (cm)	Z (cm)	Ry (°)	Rz (°)
Front	0	3.6	25	0
Back	0	−1.0	0	180
Top (right)	2.4	6.5	40	−90
Side (left)	−3.4	9.0	5	80