5-2023

Innovations in Football Protective Headgear

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On behalf of the

University of Arkansas

and the

Department of Civil Engineering

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presents his

Undergraduate Honors Thesis Defense

discussing his project entitled

Innovations in Football Protective Headgear

in partial fulfillment of an

Honors Bachelor of Science in Civil Engineering

on this date of

April 26th, 2023

3:30 PM

INNOVATIONS IN FOOTBALL PROTECTIVE HEADGEAR

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Abstract

Adding impact reduction to football protective headgear greatly decreases the force experienced by the cranium. Utilizing an iteration of the National Operating Committee for Standards in Athletic Equipment (NOCSAE) method of testing per ASTM F429, a drop tower was fabricated, and 27 drop tests were conducted upon a standard helmet (control) and the Summerlin model helmet (test), measuring the maximum acceleration experienced by each drop. Drop tests involved variable heights and test angles with three drops being made per combination. The Summerlin model drops were conducted until failure, occurring at the third 3" drop at the "front" location at an acceleration of 12.69g. The severity of neck rotation was decreased drastically by the Summerlin model. Angular testing was conducted upon the Summerlin model by comparing it to the allowable rotation of the control helmet. The percentage of rotational restriction was noted for three planes in two directions each. The Summerlin model provides a separation of loading from the neck and head and could lead to a major breakthrough in concussion prevention in the sport of American football.

Keywords: Concussion Prevention, Football Injuries, Football Headgear

1. INTRODUCTION

The implementation of load-displacing bracing connected to the helmet apparatus is a new innovation. For years, football has progressively become safer, but head injuries are a problem that are challenging even with the most modern helmet technology. The issue is not the construction of the modern helmet, but the physics behind the modern helmet preventing total protection without compromising the compact size. Altering the concept of the modern helmet by displacing impact forces through helmet-to-shoulder bracing is a potential method to maintain compact helmet design and prevent serious cranial injury. By decreasing the amount of force directly absorbed from the helmet into the cranium, the risk of cranial injury decreases. Following an inquiry about long-term head and neck injuries related to helmet technology in American football, engineer and previous Louisiana Tech football player James C. Summerlin developed a preliminary model of football protective headgear to dissipate energy absorbed by the head and neck in severe collisions. This project involved transitioning the proposed model into a testable prototype. The prototype was then tested utilizing a similar test method to that of the NOCSAE drop method.

2. BACKGROUND AND LITERATURE REVIEW

2.1 Background of Injuries

The leading cause of sport related fatalities is head trauma, and American football is the leading cause of the head related injuries out of all major sports in the United States, leading the globe in [5]. Head injuries and concussions occur weekly in professional and college football and were recently brought to light by the major head injuries of NFL players Tua Tagovailoa and Antonio Brown [4]. The risk of suffering another substantial or more severe concussion increases after previous concussion, especially if it is left untreated, potentially leading to second-impact syndrome [5]. Second impact syndrome is the rapid swelling of the brain following a second impact to a previously concussed brain that has not fully healed [5]. Difficulty with this syndrome arises from the presence of low-impact concussions, which can easily go untreated or be chosen to ignore by a player or trainer [5]. It is becoming overtly clear that football cannot be played to the highest standard of safety until advancements are made to head and neck protective gear [2].

Another major concern regarding football related concussions arises from unexpected impacts. When a player contacts another, the force of impact is combatted by a reactionary force from the helmet of the player being hit. This reactionary force is smaller than the force of the hit, but comparable. The reactionary force is equal to the mass of the object originally impacted multiplied by a vibration acceleration experienced, per Equation 2.1 [2]. This reactionary force is relatively constant regardless of the mass; therefore, the vibration acceleration is the variable value. If a player takes a blindside hit, he is unable to stiffen his neck and shoulders to aid in absorbing the force of the blow. When a player can see an impact before absorbing it, he is able to stiffen his neck, causing the mass of the reactionary force to be the entire weight of the player per Equation 2.2 [2]. When the mass at impact is much lower, the vibration (acceleration) experienced by the cranium is much higher, by a factor of approximately the player's weight divided by the weight of the player's head.

$$F_{impact} \sim F_{reactionary} \qquad \text{Equation 2.1}$$

$$F_{reactionary} = m_{body} \cdot a_{vibration} \qquad \text{Equation 2.2}$$

Not all positions are at equal risk level for head related injuries, as many positions are limited on the amount of helmet-to-helmet impacts they will take. Linemen are highly susceptible to head and neck injuries as they have the greatest amount of athletic exposure of any position on the field, as they are the only position to have guaranteed contact on every play [8]. The major concern with linemen is the lower perceived force of impact at lower velocities. As the severity of these concussions is less recognizable, however linemen can absorb much of the blow with their large body mass, which leads to issues of repetitive, undiagnosed concussions [5]. The proposed design would limit head mobility, but greatly increase impact capacity of linemen before concussion level blows. The apparatus would function similarly to modern knee braces, which limit knee ligament tears by decreasing torsional motion. Player safety is clearly the top priority. Rigorous testing must be made to ensure the product does not pose any catastrophic risks, such as severe failure of product elements leading to more severe damage to players.

2.2 Proposed Model

Previous Louisiana Tech football player and current professional engineer James C. Summerlin developed a preliminary design and testing procedure of a potential innovative design. The design includes main connectors, traveling connectors mounting to the football helmet itself, circular track allowing for rotation, tubular bearings to link traveling connectors to the circular track, and straps to mount the circular track to shoulder pads seen in Figure 2.1 [7]. Each element of the product provided a distribution of impact force away from the head and neck and into the shoulders. The idea behind the product was like that of a basic structural engineering reactions model. By placing a force absorption device on each side of the head and neck area, the force applied becomes divided over the three reactionary locations rather than solely upon the neck [7]. Preliminary research was done on the product to verify the basic model's potential. The product was dropped from various heights with a 10g failure shock recorder attached directly to the center of gravity of each helmet type, conducted with a typical football helmet apparatus and the proposed model. Based upon the original research, it was determined that the proposed headgear model nearly doubled the height needed for 10g failure, thus decreasing the amount of impact absorbed by the neck and head when using the proposed model [7].

Figure 2.1 - Proposed Summerlin Model Elemental Graphic

2.3 Determination of Test Method

Two methods of testing protective headgear are commonly used including the National Operating Committee for Standards in Athletic Equipment (NOCSAE) drop method and the Biokinetics and Wayne State University (B-WSU) pendulum method. The NOCSAE drop method involves a single accelerometer placed at the center of gravity of the testing dummy head form. The test compares shock values to the NOCSAE Severity Index at given drop heights [4]. The B-WSU method involves an impact pendulum and nine accelerometers mounted in an array within the helmet, allowing for a much more advanced analysis of impact data [6]. The impact hammer is capped by cutting the football helmet padding and shell to emulate helmet to helmet contact. The pendulum is drops at specific impact values. The array of accelerometers can detect impact forces up to 2000g, much greater than the 500g limit of the NOCSAE method [6]. Based upon scheduling and budgeting constraints, as well as the low g-force threshold of the current Summerlin model, the NOCSAE drop method was applied in this project. The NOCSAE method utilizes the procedures of ASTM F429, which requires specific elements including a precise drop tower, rotating locking arm, Hybrid III head forms, PCB triaxial accelerometers, and an MEP drop surface [3]. Given the control versus variable test type for this report, adjustments to the ASTM recommended procedures were able to be made due to time and budgeting constraints, as discussed in the Experimental Procedure portion of the report. Therefore, the test method utilized was an iteration similar to the specifications of NOCSAE and ASTM F429 rather than exact replication as seen in Figure 2.2.

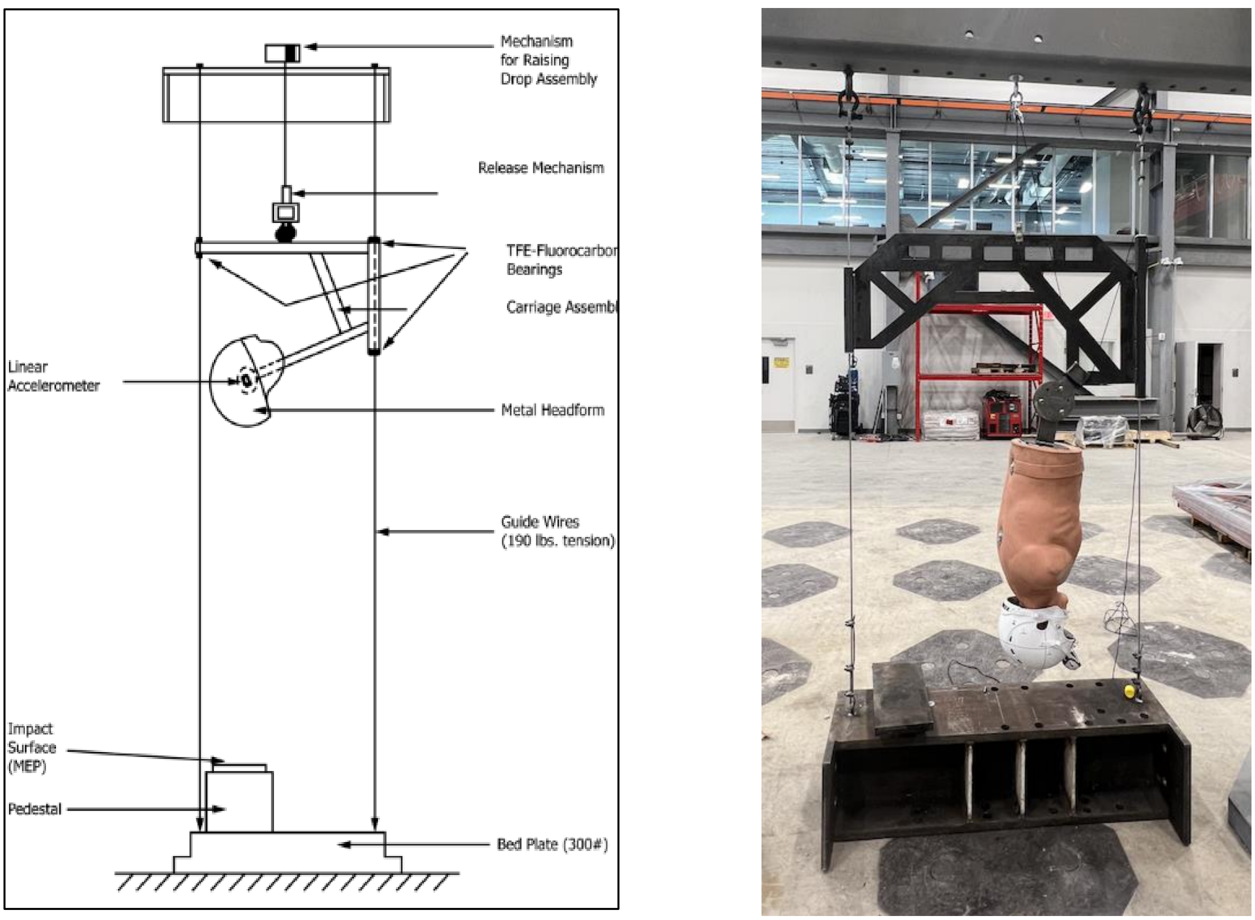


Figure 2.2 - ASTM F429 Drop Tower Assembly (left) vs. Test Fabricated Assembly (right)

3. EXPERIMENTAL PROCEDURE

Experimental procedures were conducted in approximate accordance with ASTM F429. Testing materials included the impact drop tower, Century Torso BOB dummy, Xenith Velocity 2 shoulder pads (size large), two Xenith Varsity X2E+ football helmets (size large), 3D printed impact reduction components as seen in Figure 2.3, PCB Triaxial Accelerometer (Model 356A02), aluminum accelerometer mounting arm as seen in Figure 2.4, and accelerometer software. The drop tower included two steel cables tensioned to approximately 190 pounds, steel base plate, A36 mild steel drop cage and rotating arm, polypropylene bearings, pully-trigger release, and an elastomeric rubber impact surface. The test dummy included the torso, shoulders, head, and neck. The rotating plate was riveted to the inside of the test dummy, and the remaining cavity was filled with DAP expanding foam sealant and reinforced with toggle bolts. The cage dimensions were increased from that of the ASTM to allow for the torso dummy to fit between the cables, as the full torso was required for these tests as opposed to the ASTM requiring only the head. Specific NOCSAE components of the drop cage and head forms were determined to be too expensive for testing and incapable of applying adapting to the Summerlin model. 3D printed components were created utilizing PC+PBT polymer from Push Plastic. All testing was conducted in a controlled environment at the University of Arkansas CEREC on dates from 03 April 2023 through 20 April 2023.

Figure 2.3 – 3D Printed Impact Reduction Components

Figure 2.4 – Accelerometer Mounting Arm

The Summerlin model was constructed utilizing shoulder pads, a standard helmet, and the 3D printed elements, and grade 5 steel fasteners. Two helmet apparatuses were tested including the control, a standard football helmet, and the test model, the constructed Summerlin mode As seen in Figure 2.5. A small weight was added to the control helmet test dummy to account for the absence of impact reduction technology and shoulder pads. Based upon ASTM nomenclature, the helmets were tested at “crown”, “rear”, and “front” impact locations, per Figure 3, including three impact test drops at each location [1]. The standard recommends testing the helmet at six locations, but due to fabrication constraints of the rotating arm posed from the weight of the apparatus, only 3 locations were tested. Each helmet was marked with reference marking to provide consistent impact locations. Consistent helmet positioning was ensured by the locking mechanism of the rotating arm.

To run the test, the helmet was tested at drop heights of 3 inches, 6 inches, and 12 inches. Three drops were performed at each drop height for both the control helmet and the Summerlin model.

Following each drop, the maximum acceleration and impulse duration data presented from the PCB triaxial accelerometer were recorded.

By restricting the head and neck area, the feasibility of a useful model decreases greatly. The Summerlin model allows for longitudinal rotation, but latitudinal rotation is reduced. To quantify the limit of rotation, a Johnson Angle Locator was applied to the helmet, and normal rotational motion was attempted. The allowed rotation was measured in three modes including latitudinal-straight, latitudinal-sideways, and longitudinal, per Figure 3.1. All three measurements were taken in both directions about their individual central axes. Rotation tests were conducted upon the standard helmet as well as the Summerlin model, testing three times for each location and direction and taking the average of the three runs. Utilizing the averaged values for each location and direction, rotational restriction was quantified as follows:

$$Rotational\ Restriction\ = \frac{Control\ Angle - Test\ Angle}{Control\ Angle} x100\% \qquad \text{Equation 3.1}$$

with the *Control Angle* being the measured rotation of the standard helmet, and the *Test Angle* being the measured rotation of the Summerlin Model.

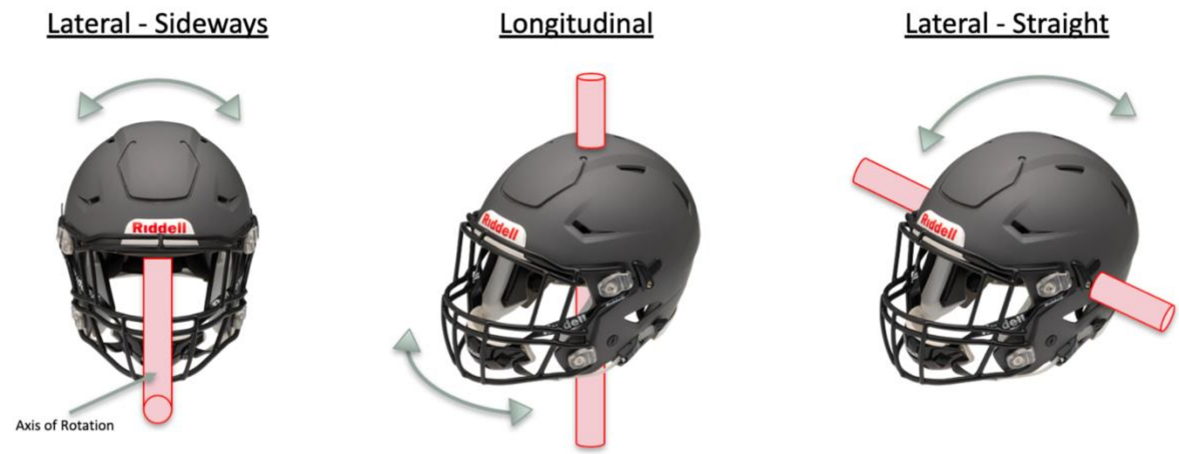


Figure 3.1 - Rotational Direction Schematic

4. RESULTS

Before any drop testing, angular testing was conducted upon both the control helmet and the Summerlin model as seen in Table 4.1 and Table 4.2. Per Equation 3.1, the average rotational restrictions in each direction were calculated. Following the helmet-specific measurements of average allowable rotation, the change in allowable rotation, and the percentage of restriction were calculated as seen in Table 4.3 and Table 4.4. The lateral-sideways rotational restrictions are concerning, as this is nearly a complete restriction of rotation.

Table 4.1 – Angular Testing Data Summary for Control Helmet

DEGREE OF ROTATION - Standard Helmet (degrees)						
Location:	Lateral - Straight		Lateral - Sideways		Longitudinal	
Direction:	Forward	Backward	Left	Right	Left	Right
Attempt 1	71.00	41.00	52.00	62.50	78.00	64.50
Attempt 2	73.00	41.00	50.00	66.00	72.00	58.50
Attempt 3	67.00	42.50	53.00	66.00	80.50	62.00
AVERAGE	70.33	41.50	51.67	64.83	76.83	61.67

Table 4.2 – Angular Testing Data Summary for Summerlin Model

DEGREE OF ROTATION - Summerlin Model (degrees)						
Location:	Lateral - Straight		Lateral - Sideways		Longitudinal	
Direction:	Forward	Backward	Left	Right	Left	Right
Attempt 1	23.00	10.00	3.00	7.00	46.50	52.50
Attempt 2	24.00	9.00	3.50	4.50	57.00	53.00
Attempt 3	27.00	8.50	3.50	7.00	48.00	45.00
AVERAGE	24.67	9.17	3.33	6.17	50.50	50.17

Table 4.3 – Comparison of Maximum Allowable Rotation Angles

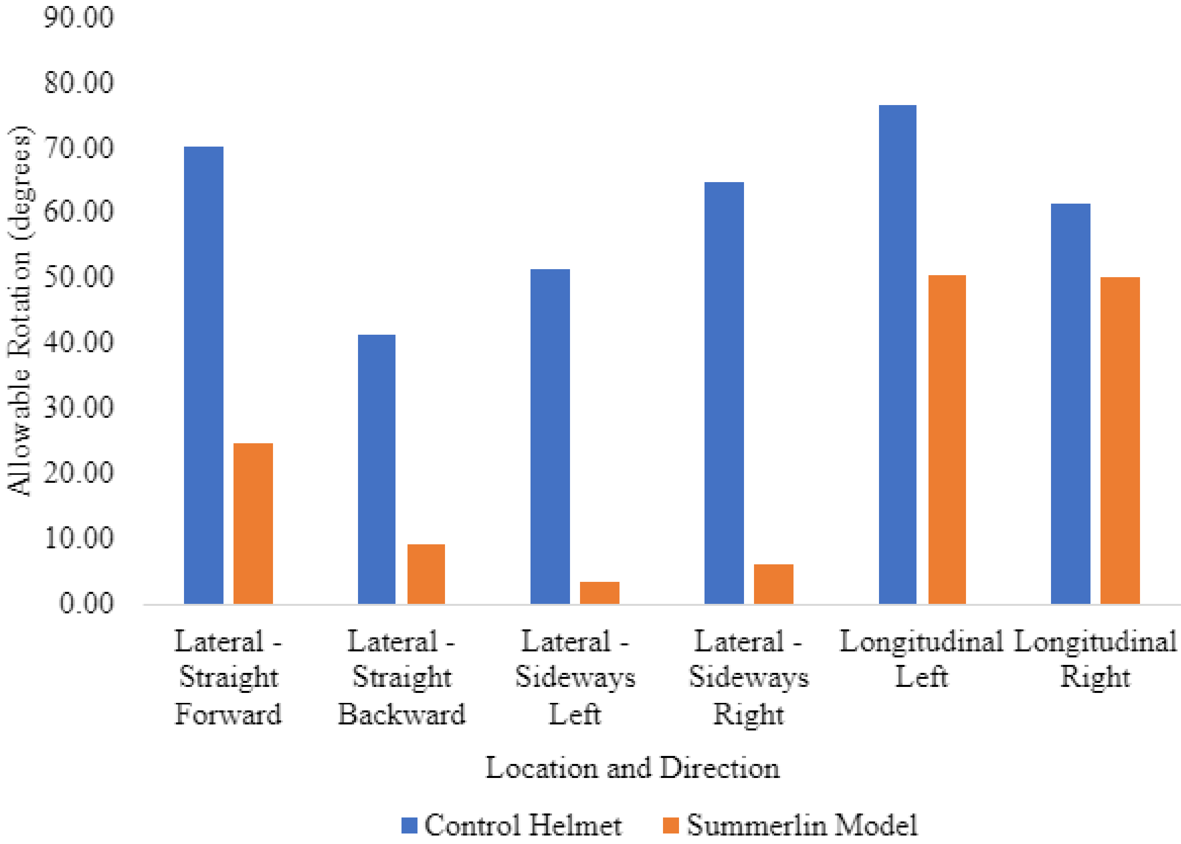


Table 4.4 – Rotational Restriction Percentages

ROTATIONAL RESTRICTION						
Location:	Lateral - Straight		Lateral - Sideways		Longitudinal	
Direction:	Forward	Backward	Left	Right	Left	Right
Attempt 1	67.61%	75.61%	94.23%	88.80%	40.38%	18.60%
Attempt 2	67.12%	78.05%	93.00%	93.18%	20.83%	9.40%
Attempt 3	59.70%	80.00%	93.40%	89.39%	40.37%	27.42%
AVERAGE	64.81%	77.89%	93.54%	90.46%	33.86%	18.48%

Maximum acceleration and duration of impulse were recorded per each drop [1]. The data collected by the accelerometer presented voltage reading in three directions (x-y-z), and the maximum value of the three was recorded. Table 4.5 contains the collected control accelerations, converted to g-force through Equation 4.1 [9].

$$a_g = a_{volt} * \frac{1000\ mV}{1\ V} * \frac{1\ g}{9.72\ mV} \qquad \text{Equation 4.1}$$

The three dash marks in Table 4.5 indicate measurements that presented an error in data collection due to faulty readings from the accelerometer. The data values presented at these locations were determined to be incorrect and excluded. Duration of impulse measurement, per ASTM F429, is to be measured when impacts impulse exceeds 50-g. For this testing, no impulse exceeded 50-g, therefore the duration of impulse was 0 for all drops.

Table 4.5 – Acceleration Testing Summary – Control Helmet

MAXIMUM ACCELERATION - Control Helmet									
Location:	Front of Helmet (g's)			Crown of Helmet (g's)			Back of Helmet (g's)		
DROP HEIGHT (in)	Drop 1	Drop 2	Drop 3	Drop 1	Drop 2	Drop 3	Drop 1	Drop 2	Drop 3
3	8.26	8.75	8.04	18.41	17.77	17.10	1.45	14.84	16.11
6	12.73	13.15	13.60	27.66	33.11	30.99	2.76	-	420.27
12	19.55	18.64	16.73	-	54.90	53.43	6.00	-	14.76

An identical data acquisition process was followed for the Summerlin model drops, displayed in Table 4.6. Failure of the Summerlin Model occurred at the third drop in the “front” location at 3”, which snapped the front-left shoulder strap as seen in Figure 4.1. Following failure of the apparatus, data was unable to be collected. Two additional drops were made post-failure from the “front” and “crown” locations at 12” to test the model for movement restriction at maximum test height, and the g-force values were collected.

Figure 4.1 – Failure Mode of Summerlin Model

Table 4.6 – Acceleration Testing Summary – Summerlin Model

MAXIMUM ACCELERATION - Summerlin Model									
Location:	Front of Helmet (g's)			Crown of Helmet (g's)			Back of Helmet (g's)		
DROP HEIGHT (in)	Drop 1	Drop 2	Drop 3	Drop 1	Drop 2	Drop 3	Drop 1	Drop 2	Drop 3
3	9.73	6.19	12.65	4.84	11.74	16.24	-	-	-
6	-	-	-	-	-	-	-	-	-
12	26.02	-	-	25.46	-	-	-	-	-

Control and Summerlin model average acceleration values can be seen in Table 4.8 and Table 4.9, respectively. It was determined that only six of the data points were comparable between the control helmet and the Summerlin model at the “front” and “crown” drop location at a 3” drop. The average acceleration values are plotted against each other in Table 4.9

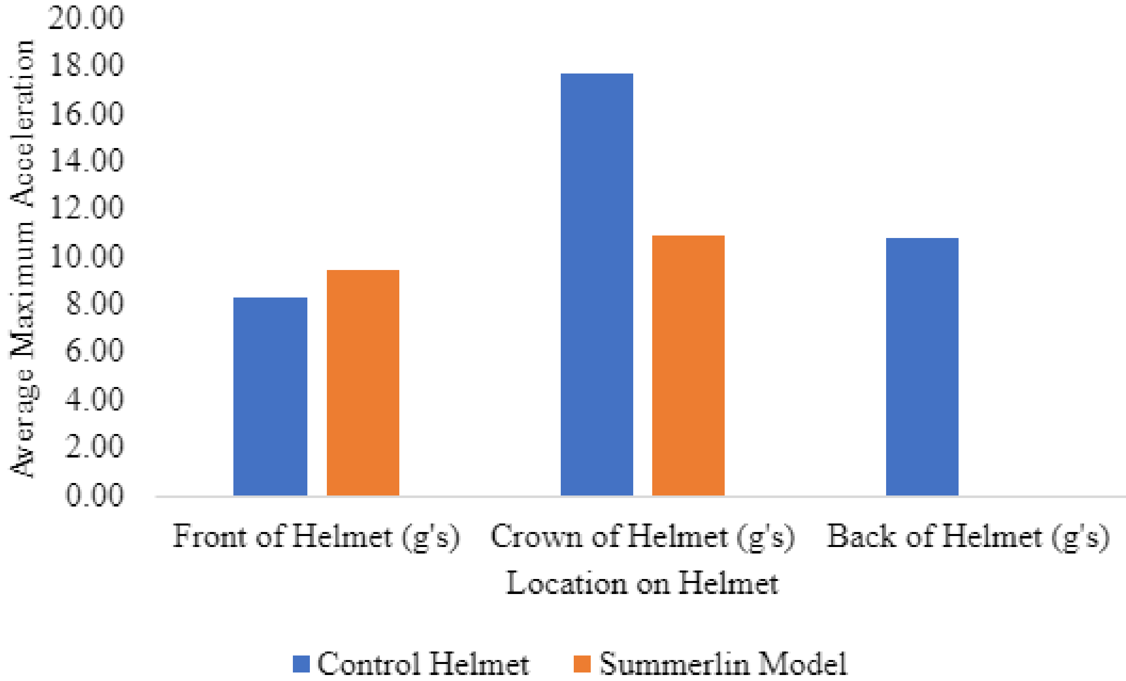
Table 4.7 – Average Acceleration Summary – Control Helmet

AVERAGE MAXIMUM ACCELERATION - Control Helment			
Location:	Front of Helmet (g's)	Crown of Helmet (g's)	Back of Helmet (g's)
DROP HEIGHT (in)			
3	8.35	17.76	10.80
6	13.16	30.59	211.52
12	18.31	54.16	10.38

Table 4.8 – Average Acceleration Summary – Summerlin Model

AVERAGE MAXIMUM ACCELERATION - Summerlin Model			
Location:	Front of Helmet (g's)	Crown of Helmet (g's)	Back of Helmet (g's)
DROP HEIGHT (in)			
3	9.53	10.94	-
6	-	-	-
12	-	-	-

Table 4.9 – Comparison of Average Maximum Acceleration at 3” Drop Height



Based upon the comparison, there is not enough data to make a definitive determination of acceleration reduction, as the “crown” location showed a decrease in acceleration, and the “front” location showed an increase. However, through the drop process, a major benefit of the Summerlin model was verified involving the restriction of extreme rotation of the head about the neck. Even post-failure the Summerlin model nearly eliminated the extreme head rotation seen in control test drops, as seen in Figure 4.2.

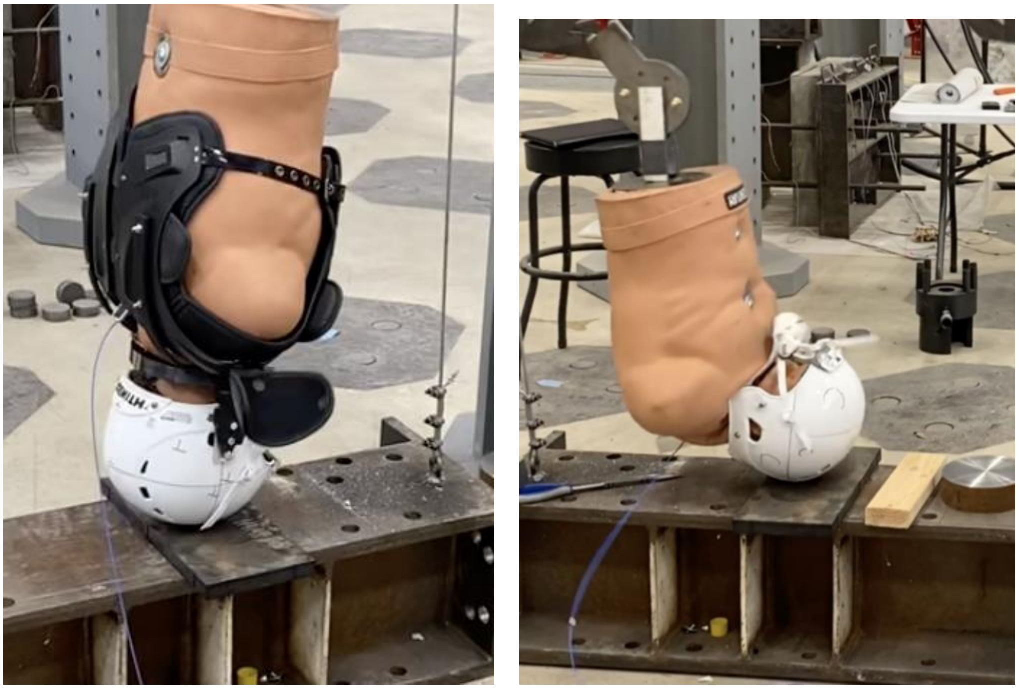


Figure 4.2 – Display of Summerlin Model Rotational Rigidity

Given the inconclusive nature and errors in accelerometer data, it is likely that the developed accelerometer mounting arm and head form adjustments lead to issues with data acquisition. The "back" location data presented multiple errors, likely caused by the extreme rotation of the head form pinching the accelerometer and applying pressure to the device and cord and must be adjusted for future testing.

5. CONCLUSIONS AND RECOMMENDATIONS

- The Summerlin Model increases the rigidity of unsuspecting players to blind-side type hits.
- The collection of accelerometer and duration of impulse was inconclusive due to early failure of the Summerlin model under drop loading.
- The current status of the model as 3D printed components is unrealistic to a factory fabricated design. Many of the plastic connections pose weaknesses to the product due to the hollow portions of the 3D printed material. The Summerlin model should be produced of a solid durable plastic with all connections and moving parts being fabricated of a strong, lightweight metal.

- The feasibility and safety of the design being implemented to skill-position players in football is very unlikely at its release, but it could be useful for linemen, who require much less neck motion.
- As stated before, budgeting and timing limited the scope of this testing greatly. To greater grasp the effectiveness and potential of the Summerlin model, it is recommended that further testing be conducted utilizing NOCSAE standard devices and the B-WSU pendulum methods by a medically focused school. Although the product greatly reduces impact forces absorbed by the cranium, the product still poses serious risk for other types of neck and torso related injuries based on its issues with mobility. A medical institution would be able to analyze both impact forces and injury prevention data of the product.
- Given the untested nature of the product, its feasibility as realistic football equipment should be tested in the future. Following insurance of product safety, the model should be presented to an actual football program, allowing for realistic field testing. Player feedback will be necessary information for the further development of the product.

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