Preventative Wrestler Headgear

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Table of Contents

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Section	**Primary Contributor**
Abstract	Marissa
Introduction	Marissa
Literature Review	
Injury Background	Marissa
Patent History	Catherine
Rules and Standards	Marissa
Project Strategy	
Initial Client Statement	Marissa
Revised Client Statement	Catherine
Initial Project Strategy	Marissa
Design Process	
Surveyed Information	Catherine
Design Specifications	Marissa
Design Verification	
Biomechanics Analysis	Marissa
Mechanical Testing	Marissa
Material Selection	Marissa
Prototype Design	Marissa
Discussion	Marissa
Final Design and Validation	
Impact Testing	Catherine
Physical Testing	Marissa
Audibility Testing	Catherine
Conclusions and Recommendations	Catherine

Abstract

The sport of wrestling has an injury rate of 21.7 per thousand exposures. This can be reduced by wearing headgear during practice, which is not done due to problems with comfort, hearing, and adjustment. As denoted by the NCAA rules committee, headgear is not required outside of competition. The team's primary objective for the project was to increase the likelihood of wear of headgear by wrestlers during practice. The team gathered information using a survey, selected materials, and established designs. The selected materials for each component were evaluated for best fit individually, then compiled into potential designs. These were then tested using the Instron, impact testing, and with testing on active participants. From these, a final design was selected that showed statistically significant improvements in comparison to the Cliff Keen Signature- the market standard- with regard to audibility and need for adjustment.

1.Introduction

The sport of wrestling is riddled with injuries and from concussions to torn ligaments, there are many risks involved. With ranging severity, injuries can hinder the productivity of a wrestlers season. An injury that is often overlooked can take a toll on the wellbeing of the athlete is auricular hematoma, otherwise known as cauliflower ear. Auricular hematoma is the collection of blood in the tissue, typically in the outer ear. This causes bubbling in the tissue which then causes swelling. Although this injury may not prevent athletes from competition, the consequences from recurring bouts of cauliflower ear can lead to anything from disfigurement, to hearing loss, to increased risk of ear infection. Auricular hematoma is the result of repeated trauma or abrasion to the pinna. The resultant injury is caused by the accumulation of serum and blood in the space between perichondrium and cartilage [5]. The damage accrued after numerous bouts of auricular hematoma can lead to cartilage necrosis and significant damage to the pinna. In addition to the temporary effects of cauliflower ear, the damage may become permanent following the hardening of the accumulated deposit under the perichondrium. The most significant permanent damage that can be attributed to cauliflower ear is loss of hearing in the affected ear. A 2015 study discussed the connection between the occurrence of hearing loss and use of wrestling headgear. The conclusions showed that wrestlers who wore headgear indicated a 19.4% occurrence of hearing loss in comparison to those who did not wear headgear that reported a 28.4% occurrence of hearing loss [16].

The main cause of cauliflower ear stems from athletes choosing not to wear headgear in practice. Although headgear is required by the NCAA during competition, in practice, the use of headgear is at the discretion of the coach and athlete. Both the 2018 and 2019 NCAA wrestling rules committee rejected the proposal of mandatory wear of headgear outside of competition. Wrestler input on the usefulness of wrestling headgear has garnered attention as generations of wrestlers have negative perceptions of headgear. The discomfort of the gear is the main complaint from athletes who would rather not use the gear in both competition and in practice. In order to address these problems, the team endeavored to create a headgear that wrestlers felt comfortable wearing even when they are not required to. This involved finding the current, most pressing problems that wrestlers have with headgear, including the headgear being more comfortable, making the headgear more stable during wrestling, and addressing cultural issues regarding wearing the headgear when not required.

A mode that has been used to monitor the prevalence of wrestling injuries is the introduction of the injury surveillance system (ISS) that was implemented in the 1980's that has been in sustained use since. The introduction of the ISS gave insight to the types of injuries and how often they occur. Patterns of injury were associated with the combative contact of wrestlers. Injury rates were significantly higher amongst the higher collegiate Division levels (I & II) in comparison to Division III [1].

Surveys were conducted to gain an understanding of the complexity of the culture surrounding headgear and any other issues that are present. Survey questions were primarily focused on the major barriers that are brought by wearing headgear in practice and competition. As the headgear was designed, the team kept this information in mind, as well as the obvious known problems with the headgear in use. Once a prototype was created, the headgear was tested for stability and strength on a mannequin during the initial design process, and future iterations were later tested on wrestlers for qualitative comfort. This allowed us to change the prototype in response to both quantitative and qualitative feedback.

2.Literature Review

2.1: Injury Background

Risk of injury is a common theme among most sports, and wrestling is no different. Wrestling has an injury problem. In season, Division III wrestling sees and injury rate of 21.7 per thousand exposures. In those, anywhere from 2-10.5% of those are injuries to the head and face. However, there are opportunities to decrease these injuries that are not being taken into account. In questionnaires distributed to 537 Division I wrestlers, only 35.2% wore their headgear outside of competition, even though wearing headgear was a statistically significant way to reduce auricular hematoma, bringing the rate from 52% to 26% [6]. The three mechanisms by which wrestlers are injured are: player contact, other contact and no contact. With this, player contact accounts for 55% of wrestling related injury [6].

Auricular hematoma, or cauliflower ear, is the result of repeated blunt force trauma to the auricula. In this, blood and serum accumulates in the space behind the perichondrium. In the span of 7-10 days post-injury, the blood and serum tend to harden, making extraction extremely difficult. The accumulation of blood has been found to inhibit circulation throughout the ear [9]. The resultant build up can lead to necrosis where the surrounding tissue begins to die as the infection overtakes the tissue. The chondroblasts in the perichondrium are responsible for the formation of the cartilage matrix. With necrosis, the chondroblasts are inhibited and the cartilage matrix breaks down.

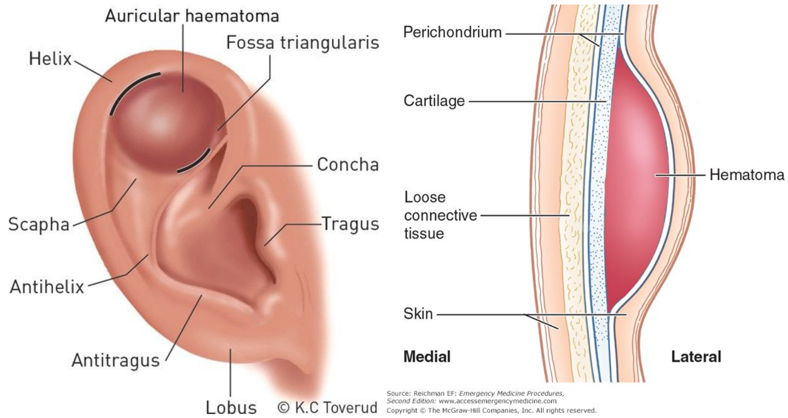

Figure 1:Anatomy of Auricular Hematoma- adapted from McGraw-Hill Medical

A major area of concern with current headgear is that athletes cannot hear their coaches while wearing headgear. The noise level at sporting events varies widely throughout both professional and collegiate levels. More often than not, the noise is measured in decibels and recorded at sporting events. At the 2019 NCAA Division III National Wrestling Tournament the noise level in the Berglund Center (Roanoke, VA) was measured to be between 87.6 and 94.8 decibels. This is similar to the measured values at collegiate and professional basketball as well as football according to Starkey Hearing Technologies. Any noise level that exceeds 120 decibels is considered to be damaging to hearing. There is a variance in the noise level that exists based on the location in the building that a viewer or athlete is, as the floor level was slightly quieter than in the stands.

2.2: Patent History

The first patented headgear, as shown in Figure 1 in the United States was in 1959. It looks similar to current headgear, in that it has pads over the ears with straps supporting them. The main areas that the headgear was attempting to address was similar to what this project is attempting to address- to make headgear that is protective and comfortable. The main features of this design are that all of the straps around the head are adjustable to account for different sizes of the head. There is also thought put into the construction of the padding that covers the ears, in order to avoid discomfort and injury upon impact. [10]

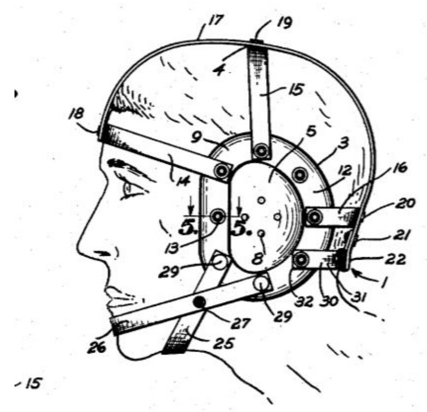

Figure 2. First Patented Wrestling Headgear [10]

The next patent update shown in Figure 2 comes in 1967, with a proposed update of an added hole in the ear padding in order to increase ventilation of the ears and improve the hearing of the wearer while using headgear. In every other way, it is identical, as noted in the patent. [11]

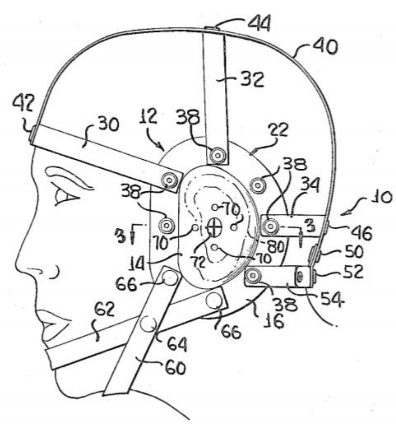

Figure 3. Change to first headgear for ventilation [11]

The next update occurs 34 years later, in 2001. This headgear is different is several different ways to the 1967 version. The number of straps is greatly reduced, with one over the chin, one over the forehead, and one behind the head. This can be seen in Figure 3. The goal of this headgear was to find a less unwieldy way to put on and use headgear, as well as to improve the fit and protection of the ear pads for a variety of wrestlers. [12]

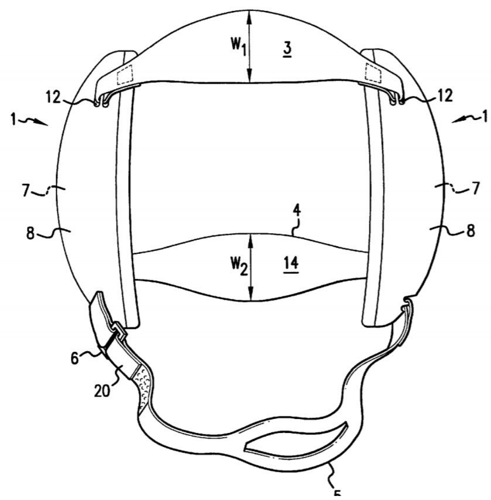

Figure 4. Modern Headgear Design [12]

A patent 2 years later adds more straps back into the design, with two behind the head, one over the top of the head, one on the forehead, and one on the chin. This headgear is shown in Figure 4., and was designed to make headgear more comfortable and fit better by adding the additional straps and making them fully adjustable with D rings. It was also meant to address an issue at the time, which was that in order to be adjusted, headgear was taken off, adjusted, and then put back on, which was tedious and time consuming. This design aimed to maintain the security of those straps while enabling faster adjustment. [13]

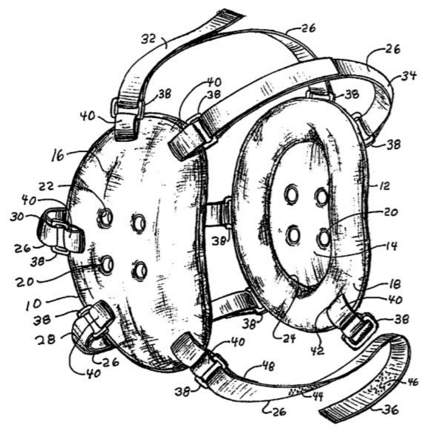

Figure 5. Easier Adjustment Headgear [13]

In 2014, headgear with protective pads over the entire head, as opposed to simply the ears was patented. In this design there is padding over the forehead area, extending over the top of the head and to the back, though there continues to be a chinstrap, straps over the top of the head and a strap at the back of the head for comfortable fit. The overarching goal for this headgear is to prevent the common occurrence of concussions and other impact based injuries in wrestling. J. DaSilva, "Wrestling Headgear," 13-Nov-2014.

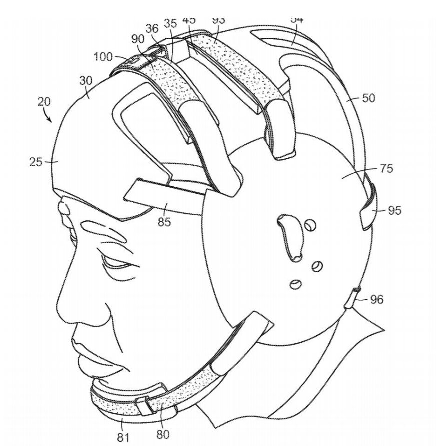

Figure 6. Additional Protection for Headgear [14]

The culture surrounding wrestling has been garnered over generations as headgear has evolved. Over the years, the stigma surrounding the use of headgear has impacted the mentality of teams as they often choose not to wear the gear when not required. The impact of the stigmas has led to cauliflower ear being flaunted by athletes, as a badge of honor.

2.3: Rules and Standards

Within the arena of wrestling, there are numerous but varying rules and regulations that are published yearly by the NCAA Wrestling Rules Committee. The Committee consists of representatives from each NCAA Division as well as Athletic Directors and Coaches from different institutions.

TABLE 1: NCAA Wrestling Rules Committee 2018

Division	Name	Institution	Conference
FBS	John W. Smith	Oklahoma State University	Big 12 Conference
FCS	Matt Valenti	University of Pennsylvania	The Ivy League
FCS	Jack Maughan	North Dakota State University	The Summit League
DI	Jason Coomer	Southern Illinois University Edwardsville	Ohio Valley Conference
DII	Cy Wainwright	Newberry College	South Atlantic Conference
DII	Jason Warthan	University of Indianapolis	Great Lakes Valley Conference
DIII	Brad Bruhn	State University of New York at Cortland	State University of New York Athletic Conference
DIII	Lonnie Morris	Johnson & Wales University	Great Northeast Athletic Conference

The division specific committees are divided by each of the three NCAA Divisions and consist of coaches and athletic directors. These committees oversee the divisions and their constituents in rulings throughout the season. In addition to the Division 1 representative, there are other representatives from two independent leagues: FCS and FBS. The representation of different league constituents gives a broad backbone to the discussions surrounding the rules committee voting on a yearly basis. The table below lists the representatives from each of the six governing regions of Division III Wrestling.

TABLE 2: Division III Wrestling Committee 2018

Name	Institution	Conference
Jeff Swenson	Augsburg University	Minnesota Intercollegiate Athletic Conference
Eric Van Kley	Central College (Iowa)	American Rivers Conference
Eric Walker	Elizabethtown College	Landmark Conference
Roger W. Crebs	Lycoming College	Middle Atlantic Conference
Ron Beaschler	Ohio Northern University	Ohio Athletic Conference
Scott Honecker	Williams College	New England Small College Athletic Conference

2.4: State of the Art

The state of the art for wrestling headgear is in a constant state of evolution as newer technologies are implemented. With this, there are many tried and true brands that teams across the country tend to use like Cliff Keen, and LDR (Leader headgear). With this, there are many other options for headgear on the market.

There are two prominent designs for headgear that is currently used on the mat (See Table 3). The first being very similar to the originally patented style that is composed of two ear covering cups and numerous straps around the top and back of the head and chin. These straps are adjusted in typically in two ways. The first being a tension strap that is either tightened through a metal closure much like a belt or a metal clasp that clips into a snap on the exterior of the headgear. The second type of closure is Velcro which is very easily adjustable, but tends to be easily moved in competition making it a lesser desired choice for athletes. The frequent adjustment of the Velcro is often hindering to the productivity of the competition and slows the speed of matches taking away from the amount of time competitors have to acquire points.

The newest headgear to hit the market in November of 2018 is the Mercado by the company Batsoi. This headgear was designed by an NCAA Division 1 wrestling alumni who believed that this improved headgear would better protect from concussions and other head injuries. Unlike other headgear used in collegiate wrestling, the Mercado has the fit of a helmet rather than simply ear covers. This change in technology will likely impact the viewpoint that current athletes have on wear.

In September of 2018 the company Thoroughly Reviewed, released an article that was a comprehensive review of wrestling headgear that is on the market and in use. Below is an adapted table to show the variance between the top headgear on the market.

TABLE 3: Headgear Comparison

	Tornado (1)	Conquest (2)	Aggressor(3)	Twister(4)	AE100(5)
Brand	Cliff Keen	ASICS	ASICS	Cliff Keen	Adidas
Audibility (%)	80	80	70	80	70
Straps	5	5	5	3	5
Material	Polypropylene	Polypropylene	Polypropylene	Polypropylene	Polypropylene
Warranty Years	1	1	1	1	2
Image					

Table 3 showcases the five top ranked headgear that is available as of now. As one can see, there are a number of headgear missing from this list, in particular the Bats-toi and LDR. Based on information gathered from the background of the article, these are left out as they are not top-selling on Amazon.com. The price of the Bats-toi Mercado which is being released to the public in November of 2018 will be in the range of $120-140. In addition, the LDR headgear sells for $60. While this may not be exceedingly expensive, it lies outside of the typical price range for wrestling headgear. Based on the above information and other observations within wrestling, the market standard headgear is the Cliff Keen Signature as it is predominantly used by collegiate wrestlers.

3. Project Strategy

3.1: Initial Client Statement

When beginning this project, the initial client statement was to create headgear that prevents common wrestling injuries that wrestlers will wear even when not required. Based upon that statement, the team formed design requirements for creating headgear. Those are described below:

TABLE 4: Objectives

Objective	Description
Maintain market standard or better strap strength	The breaking point of the straps that secure the headgear to the head
Maintain market standard or better ear cushioning	The ability of the headgear to absorb impact and twisting forces on the ear
Lower rate of adjustment compared to market standard	How much of practice is spent adjusting headgear per hour
Lower time to adjust headgear	How much of practice is spent adjusting headgear per hour
Improve comfort rating compared to market standard	Rating of comfort as given by wrestlers after wearing headgear
Maintain or improve audibility compared to market standard	Ability to hear beeps and instructions given different levels of ambient noise
Stay at a reasonable price given the current market	$60 is considered expensive for the current market, average is around $40
Improve stated likelihood of wear compared to market standard	As determined by yes/no question asked of wrestlers having seen/used headgear
Improve aesthetic score compared to market value	Rating of aesthetic as given by wrestlers having seen/used headgear

3.2: Revised Client Statement

With any national college sport, the National Collegiate Athletic Association (NCAA) is the governing body with regard to rules and regulations. According to the NCAA for all Divisions, the requirements for headgear in competition is as follows:

Wrestlers shall wear wrestling ear guards designed by the manufacturer for the sport of wrestling that are rigid and padded, which provide:

a. adequate ear protection;

b. no injury hazard to the opponent; and,

c. an adjustable locking device to prevent it from coming off or turning on the wrestler's head. [3]

This ruling is the basis by which all wrestling headgear must adhere. The NCAA uses this regulation across all divisions of collegiate wrestling. This is the standard by which this project aims to follow. Based upon the guidelines and our objectives, the team determined that our revised client statement was to design and fabricate a new wrestling headgear that increases the likelihood of wear during practice, thus preventing the prevalence of cauliflower ear, while in adherence to NCAA guidelines. The benchmarks denoted below stem from a biomechanic analysis of wrestling discussed in section 5.1.

Table 5: Revised Objectives

Objective	Description	Benchmark
Maintain market standard or better strap strength	The breaking point of the straps that secure the headgear to the head	Greater than or equal to 1800 N
Maintain market standard or better ear cushioning	The ability of the headgear to absorb impact and twisting forces on the ear	Greater than or equal to 2800 N of impact force
Lower rate of adjustment compared to market standard	Number of adjustments in a practice session	Minimize number of adjustments compared to market standard (<7 per 25 minute intervals)
Lower time to adjust headgear	Number of points of adjustment on the headgear	Minimize the number of adjustable locations compared to market standard (<5)
Improve comfort rating compared to market standard	Rating of comfort as given by wrestlers after wearing headgear	Receive a greater comfort rating from wrestlers based on a likert scale questionnaire
Maintain or improve audibility compared to market standard	Ability to hear beeps and instructions given different levels of ambient noise	Record a lower level of volume audible with ambient noise (45 decibels) compared to market standard
Stay at a reasonable price given the current market	$60 is considered expensive for the current market, average is around $40	Maintain or lessen the average price of $30-$40 for the prototype
Improve stated likelihood of wear compared to market standard	As determined by yes/no question asked of wrestlers having seen/used headgear	Determine the likelihood of wear using a likert scale questionnaire
Improve aesthetic score compared to market value	Rating of aesthetic as given by wrestlers having seen/used headgear	Determine the aesthetic score based on the likert scale questionnaire

3.3: Initial Project Strategy

In order to accomplish our project goals and objectives, there are a number of steps that the team took. The first being establishing background research. In doing so, the team gained a baseline of knowledge about the origin of wrestling headgear and the means by which athletes and coaches interact with the devices. Following this, two surveys directed towards the audiences of coaches and athletes by which the team will furthered the team's understanding of the culture and use of headgear in and out of competition.

As of now, there is no document research on impact in wrestling, or analysis of wrestling biomechanics. In order for the team to accurately represent the amount of force the new device will be required to withstand, the team conducted studies of wrestling and computed and extrapolated the biomechanical model for the sport at each weight class. The team analyzed wrestling biomechanical models based on weight class of collegiate wrestlers. This provided a better understanding of the force distribution that athletes undergo in competition and practice.

Current product testing allowed for the team to create a benchmark for the materials on the market that are used in headgear. The evaluation of these materials gave the team an opportunity to identify concerns and flaws with the implementation of the gear. The team then defined areas which the team hoped to improve. Following the gathering of information, the team will work to brainstorm possible solutions and preliminary designs for the intended outcomes defined by client research. The intention of this stage was to compare and contrast possible ideas that can then be created and eventually tested in the prototyping phase. The intent of the prototypes was to create and evaluate one or more of the ideas that have been discussed. In doing so, the team ranked and decided to pursue one of the designs.

To evaluate the success of the prototype, the team implemented a battery of tests using the prototype and the baseline headgear to create a valid comparison. Comparing the baseline and the prototype performance will guide the team to either move forward with the prototype or go back to the brainstorm and reevaluate the goals and needs of the final design. The limitations with, however, are mainly with regard to time. The goals and timeline that have been outlined by the team intend on promoting productivity and allowing for reevaluation when testing occurs. To best succeed, the team must meet and/or surpass the baseline that is derived from initial testing of current market technologies.

4. Design Process

4.1: Surveyed Information

The desired outcome of this project is to reduce factors that cause the prevalence of auricular hematoma in wrestlers, such as not wearing headgear, by addressing common problems with headgear such as the need for constant adjustment, audibility problems, and overall discomfort. The baseline understanding of the gaps in protection and additionally the current culture surrounding the use of headgear. The surveys can be found in Appendix B. In order to address these problems, headgear needs to be adjusted less in a standardized workout, perform better in a standardized 'beep test', and score better in comfort and aesthetics, as compared to the market standard.

In addition to the surveys, a number of interviews with administrators, coaches and athletes will further aid the teams comprehension of the needs of the product that the team intends to create. While the conversations gave a basis by which the team could begin to discuss solutions, personal observations of wrestling better quantified the problem.

The team distributed a survey (Appendix B) to collegiate coaches across the united states at all NCAA Divisions and NAIA schools. The responses were gathered into a document, and student-athletes and coaches were given the opportunity to share the school that they attend. This information was used to ascertain the reach of the survey and validate that the sample size of answers did not stem from one team, or one region.

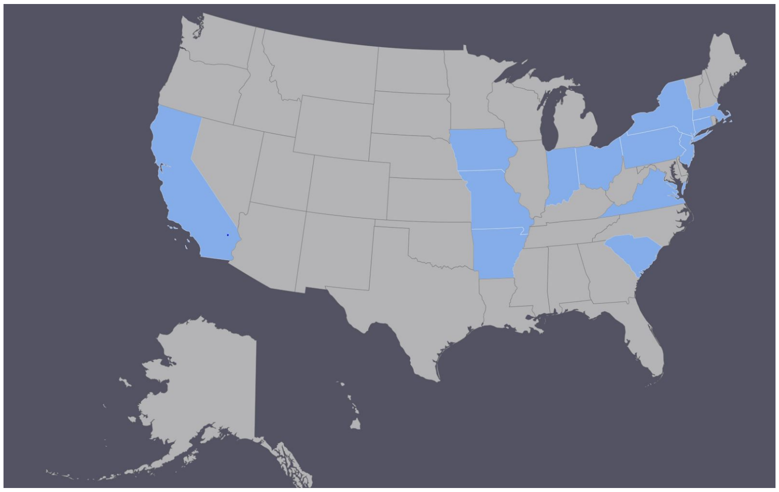

Figure 7. Map of Respondents Locations (blue)

Two-hundred and twenty nine athletes responded to the survey from thirteen states and gave insight as to what requirements their teams have for headgear in practices, as well as their opinions regarding the gear itself. We found that 67% of respondents were on a team that did not require headgear at practice. 33.3% of respondents reported that they never wore headgear during practice. Shockingly, 61.1% of respondents have experience auricular hematoma at least once. As shown in Figure 8, requiring headgear during practice increases the percentage of reported ‘Never’ and ‘Once or Twice’ responses, while teams that didn’t required headgear had higher percentages of ‘Three to Five Times’ and ‘More than Five’ responses.

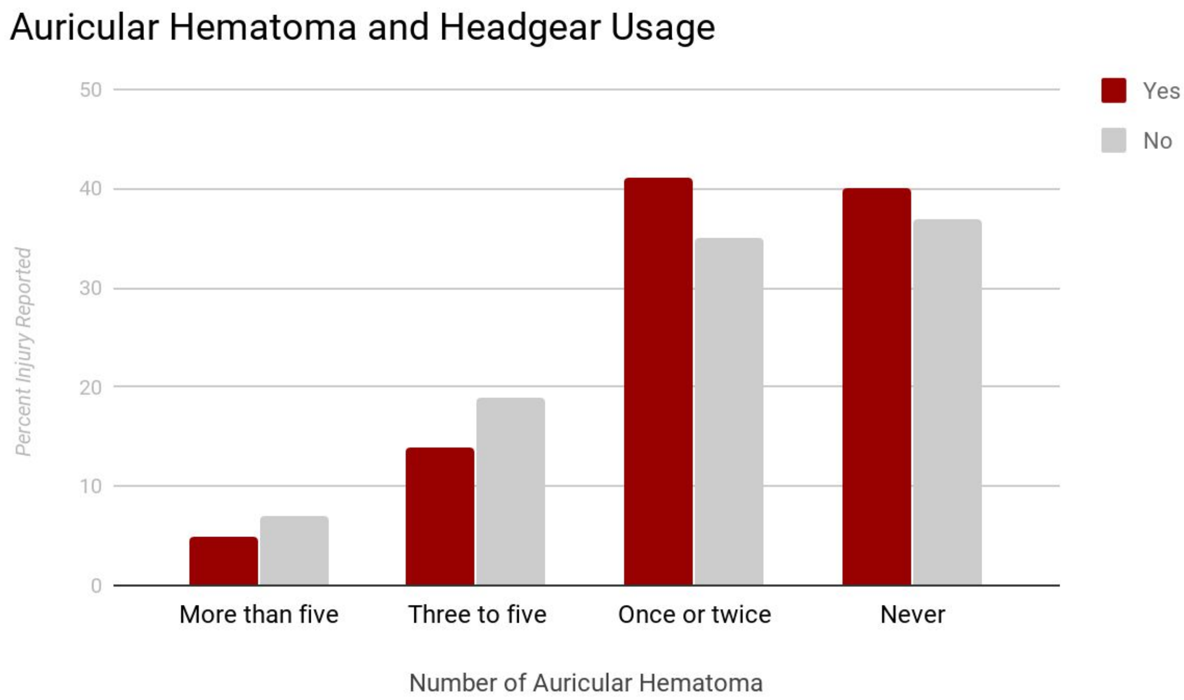

Figure 8: Comparison of reported auricular hematoma by requiring headgear at practice

83.2% of responders said that they would consider wearing headgear during practice if it prevented auricular hematoma and didn't hinder productivity. By sorting the complaints into general groups, it was also possible to determine the greatest barriers to consistent headgear usage. 39% of applicants reported that the headgear was constantly uncomfortable, while 24% reported hearing issues and 44% reported complaints with the adjustment or slipping of the headgear and straps during practice.

4.2: Design Specifications

There are a number of specifications by which the team took into account as the team developed a new headgear. The process for identifying and ranking those specifications are detailed in Table 6. The main materials that headgear is constructed of are polyester and polypropylene. Both of these materials have varying properties. The mechanical properties are crucial for the protection of the athlete, as a soft material would not withstand the same pressures that a semi-hard plastic would. Polypropylene has a high tensile strength which lends it to work well with high impact- this is used on the outer cup of the headgear. While the strength of polypropylene lends for it to protect the user, polyester provides elasticity that allows for movement in the gear adding comfort. The way that headgear fits is key to the comfort of the athlete. Although headgear is not worn merely as an accessory, there is an aesthetic component which wrestlers tend to have a negative opinion of the way that gear looks. In addition, cauliflower ear can be seen as a badge of courage for many athletes.

TABLE 6: Decision Matrix

	Weigh t	**Audibility**	**Ease of Adjustment**	**Comfort**	**Adjustability**	**Aesthetics**
Survey	2	1	1	1	1	0
Interview	3	1	1	1	1	1
Literature	1	1	1	0	0	0
Total		3	3	2	2	1
Weighted Total		**6**	**6**	**5**	**5**	**3**

The team has a few financial considerations to work with. First of all, the team has identified price as a limitation in the final design, in that interviews with wrestling coaches have shown that the average prices for helmets are from 30 to 40 dollars and $60 is considered prohibitivly expensive for headgear. Thus, it is essential that the final price for our headgear remains competitive with market standards. In addition to that consideration, the team also has a

$500 budget and thus must remain aware of spending in testing current helmets and in the creation of the prototype.

The team composed a timeline (Appendix C) for the duration of the project to stay on track. The timeline aligned with the overall goals of the project, ensuring that important landmarks were met to meet set deadlines. As the project progressed, these goals were re-evaluated for progress and achievement.

5. Design Verification

5.1: Wrestling Biomechanical Analysis

To justify the forces experienced when wrestling, an evaluation of typical biomechanical functions of the athlete was completed. These revealed the maximum theoretical force values which a wrestler would experience in both practice and competition. The analysis was completed based on weight class ranging from 125 pounds to 285 pounds based on distances from wrestler-wrestler and wrestler-mat.

$$F = m * A \qquad (1)$$

The average lunge speed used was approximately 13.8 km/hr which is attributed to the forces exerted. Using motion analysis and fiduciary markers on wrestlers in live wrestling, the average distance between wrestlers was determined to be 1.5m. Inputting this data into equation 1, the values in table 7 were calculated.

TABLE 7: Calculated Maximum Forces

Weight Class	**Approx. Max Force (N)**	**Weight Class**	**Approx. Max Force (N)**
125	1350	**165**	1782
133	1436	**174**	1879
141	1522	**184**	1987
149	1609	**197**	2127
157	1695	**285**	3078

From Table 7, the maximum calculated force exerted would be 3078 N. This value is extremely high and occurs minimally in competition. Based on the average of the above calculations, the expected maximum exerted force would be 1846 N. This average value was used as the benchmark for measurement shown below in mechanical testing.

5.2: Mechanical Testing

To test the viability of the materials in consideration for the proposed headgear, a number of tests were conducted in which various measures of the materials mechanical properties were ascertained. These tests were conducted using the Instron 5544 and force plate data collection.

The Instron 5544 requires the preparation of a Bluehill method which was prepared following the standard tensile testing procedure. Specimen properties were set to a rectangular geometry and physical measurements were set to record data for time(secs), extension(mm), load(N), tensile strain, tensile extension(mm), and tensile stress(MPa). The graph was set to have an x-axis of time(secs) and a double y-axis of load(N) and extension(mm) and the test was set to end when the load was back at 0 N, which occured when the specimen was broken. Before beginning the tests, tare loads of approximately 5 N were applied to each sample section to put pressure on the sample and ensure the specimens were stable and would not slip. The displacement was zeroed and a digital caliper with a ±0.01 mm accuracy was used to measure the width and thickness of each specimen section as well as the length between the two grips, gauge length.

The pre-calculations (1) for the specimen were evaluated using the UTS of each material to determine the maximum force. Since the max force of each sample did sometimes exceed the max load cell capacity of the Instron (2000N) and was greater than 1% of the load cell’s full range (20N), some samples were not able to be tested to failure using the machine. The pre-calculations determined that some of the materials exceeded the max load cell capacity of the

Instron, and therefore, were not tested. This however, falls within the standard for the expected maximum force withstood when using wrestling headgear which is 1846 N.

$$F = UTS * A(w * T) \tag{2}$$

Materials were cut, or prepared to fit in the standard grips for tensile testing in the Instron 5544 in accordance with ASTM D5034. The shape was reminiscent of the dog bone sample with a rectangular geometry.

TABLE 8: Material Specifications

Material	**Length (mm)**	**Width (mm)**	**Thickness (mm)**
Polyamide (Nylon)	157.38	24.63	1.24
Polypropylene	165.44	25.30	1.63

The team designed a number of prototypes prior to settling on the final design. In order to accomplish this, the team investigated a number of materials to construct the final prototype. The prototype itself was divided into three components: ear cups, straps & closures. The main components stem from the deconstruction and evaluation of the Cliff Keen Signature headgear. Each component was given multiple material options so the team could evaluate each on their own, and combine the most viable from each category to construct the final prototype.

5.3: Material Selection

5.3.1: Straps

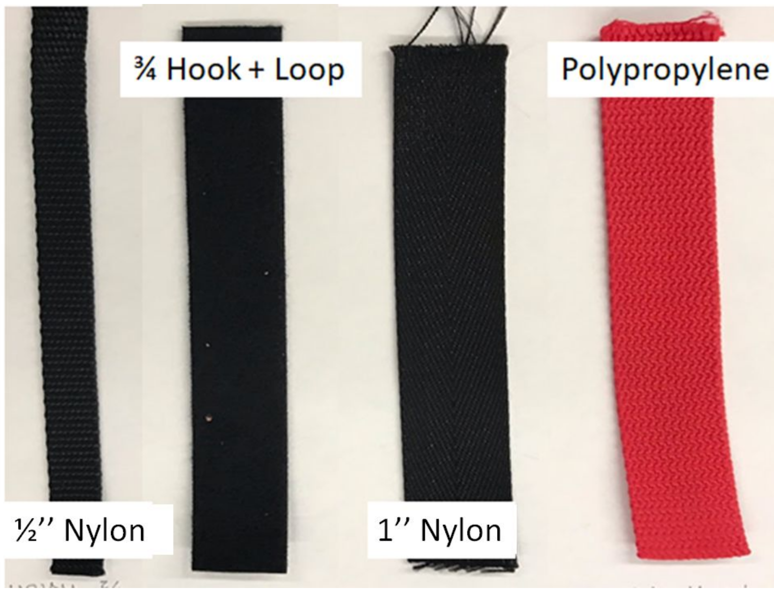

Figure 9: Strap Options

Four materials were considered viable options for the new straps on headgear based on research completed in the early stages of the project. The team drew from ski straps in addition to fashion headbands and elastics. The properties of these materials were considered with regard to the security, strength and comfort of the material. Testing of strength described above gave light to which material would be the highest strength while also providing comfort and security when tightened.

5.3.2: Ear Cups

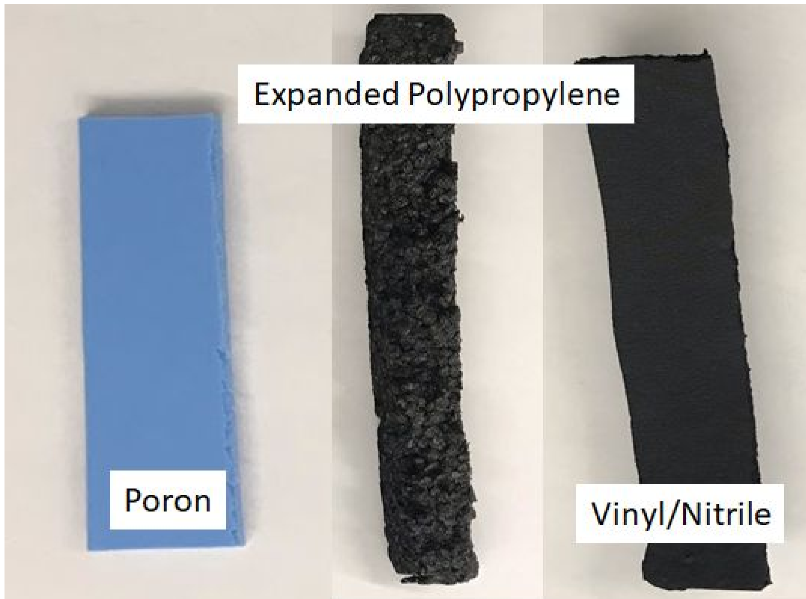

Figure 10: Ear Cup Material Options

When designing the prototypes ear cup, it was known that the team intended on eliminating the plastic insert that exists in the current market standard produced by Cliff Keen. The plastic cup is the main cause of audibility issues as well as discomfort. To accommodate this change, the strength and impact prevention of the new material had to be much greater than the market standard. Three materials were chosen based on the materials used in other headgear and helmets for varying sports, and altered to be fitting for wrestling.

The first material was expanded polypropylene which is a denser version of styrofoam consisting of small pellets bound together to create a certain shape. It is not very dense, as it has large pores between each pellet. This caused the material to withstand low loads of impact, allowing the team to rule expanded polypropylene out as an option for the final prototype. The remaining two options- vinyl nitrile, and poron- showed much greater viability than the initial sample. Poron, although thin, could be layered into varying shapes that were reminiscent of the shape of a human ear shown in Figure 11. Further, the material's ability to disperse forces upon impact was greater than the earlier design. Finally, vinyl nitrile was tested. The sample proved to be very capable of dispersing forces upon impact, and was chosen to create a secondary prototype. The quality of the material led to the design to require a single piece of the material for each ear cup. This led to a thinner headgear that provided the same level of protection, while removing the bulk of the current market standard.

5.3.3: Closures

Closures for current headgear consist of buttons, d-rings and velcro. The majority of the closures are difficult to adjust as they are encased in between the foam exterior of the ear cups and the plastic interior of the ear cups. As adjustability was a cause for concern, the team looked into three options including buttons, d-rings and a cam. The cam idea stemmed from the cam that is used to secure boat straps for transport. When cinched, the cam is immovable which is ideal for the headgear closure as once locked, the athlete would want as little adjustment as possible during both competition and in practice.

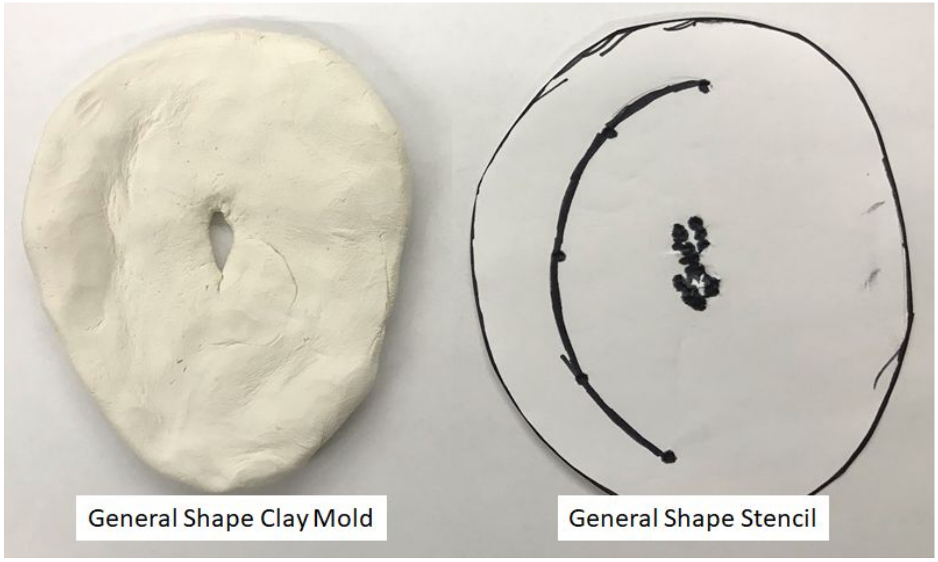

Figure 11: Ear Cup Construction

When the team began evaluating the fit and the shape of the headgear, they decided to look into gear that mimicked that of the human ear with appropriate placement of the holes designed to improve hearing. The designs shown in Figure 11 are the rough design concepts that the team evaluated created from clay as well as paper that was used to measure the cut material for the prototypes.

5.4: Prototype Design

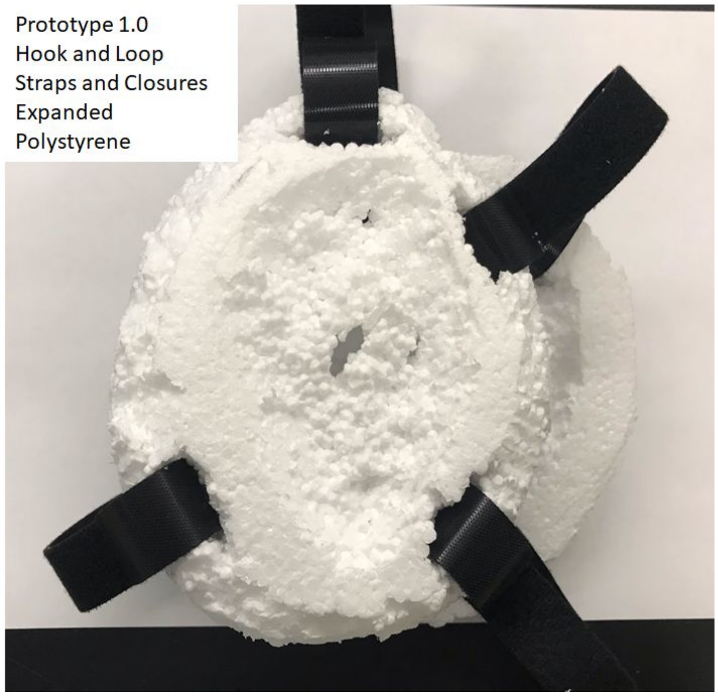

Figure 12: Prototype 1.0

The first prototype shown in Figure 12 was constructed using expanded polystyrene and hook and loop fasteners. This prototype was used to evaluate the feasibility of the ear shape design.

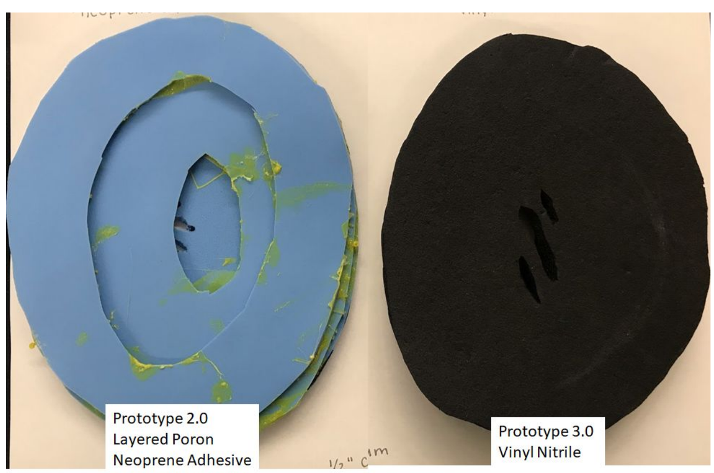

Figure 13: Prototype 2.0 & 3.0 Ear Cup

The second prototype was constructed using layered poron sheets bound by neoprene adhesive. The poron sheets were layered as the individual sheet was exceedingly flexible, but once compiled in three layers, the rigidity of the ear cup reflected that, which the market standard headgear. The intent of the rigidity was to mimic that of current headgear while removing the need for a hard plastic insert.

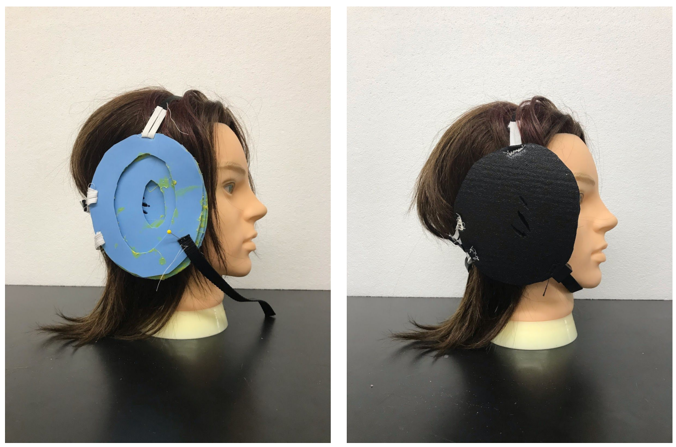

Figure 14: Prototype 2.0 (left) & 3.0 (right)

The third and final prototype was created using vinyl nitrile. This was chosen as a viable option as the material performed the best in the impact testing as shown in Figure 14. The material absorbed the impact the best, as the porosity of the material distributed the weight-force the most evenly of the considered material options. In construction of this prototype, nylon thread was used to sew the elastic and nylon straps in predetermined locations.

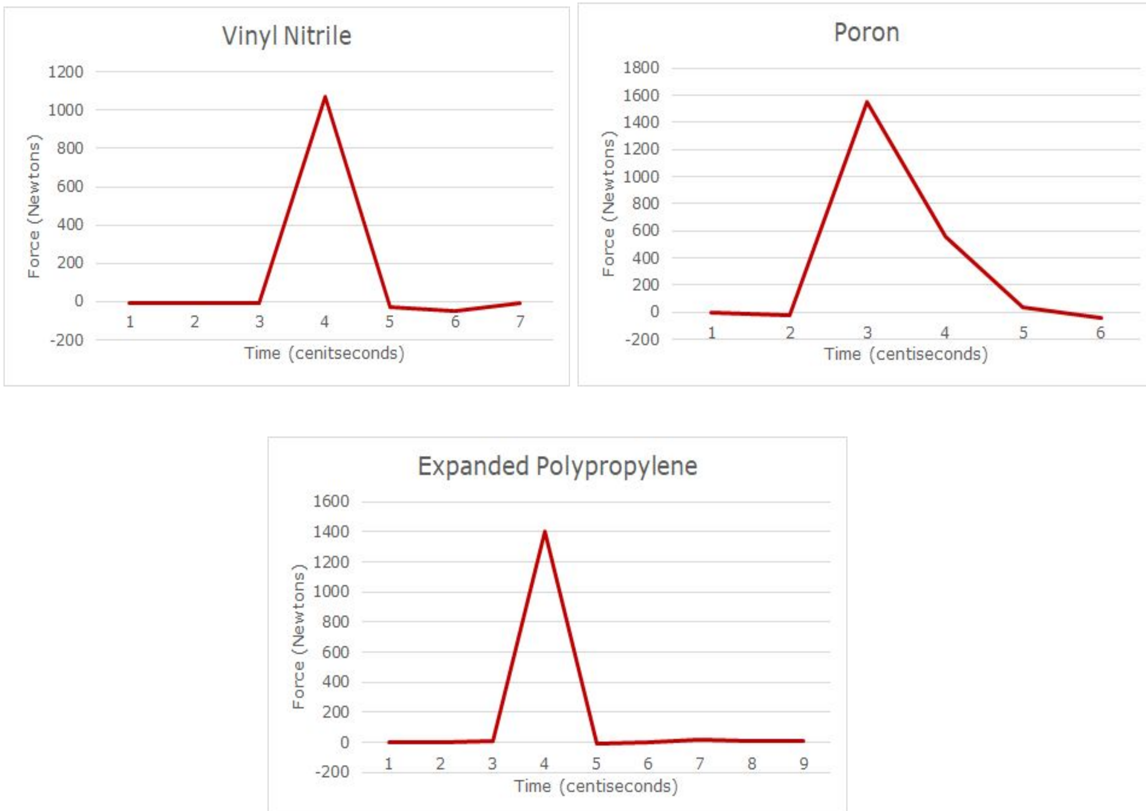

Figure 15: Material Impact Testing Results

In Table 9, the team evaluated the designs based on five main criteria. The highest weight criteria was comfort, which both of the prototypes met as they were considered more comfortable in comparison to the market standard. Following this, the impact testing results yielded that the vinyl nitrile met the standard and was credited with a tally in that category while the poron was lacking in the impact tests. Further, manufactuability came into play, and the layered poron prototype was exceedingly difficult to assemble as the layers and neoprene adhesive made it difficult to sew the straps and cam to the device. Due to this, the vinyl nitrile prototype again beat the poron counterpart in the category of manufacturability. The cost of the poron prototype was significantly more than the cost of the vinyl nitrile prototype giving the vinyl nitrile option the better ranking for this as well. Finally, with aesthetics, the vinyl nitrile continued to exceed the poron counterpart as it looked more appropriately like a headgear with a much cleaner design.

TABLE 9: Prototype Decision Matrix

Criteria	**Weight**	**Layered Poron**	**Vinyl Nitrile**
Comfort	5	1	1
Cost	2	0	1
Manufactuability	3	0	1
Impact Testing	4	0	1
Aesthetics	1	0	1
Total		1	5
Weighted Total		5	15

A major area of concern with current headgear is that athletes cannot hear their coaches while wearing headgear. When determining improvements in audibility, the team was careful to consider the variant levels of noise in practice and competition, and how it impacts the athlete.

6. Discussion

In understanding the market standard, the price of headgear currently being sold is important to consider. The variance in market prices of wrestling headgear is exceedingly large, as newer, more developed headgear have had a spike in price. The newest gear for sale as of November 2018 is the Mercado which sells for close to $200. The average headgear is under fifty dollars. In constructing the prototype, the material cost and difficulty of manufacturing was taken into consideration.

The consideration of environmental impact is something that is challenging. None of the materials are degradable, however they are able to be used for a significant period of time. The teams prototype requires less materials and therefore less waste than the current market standard that was defined earlier. In eliminating the plastic interior of the ear cup, the team was able to avoid using excess material to construct the final design for the newer headgear.

The wrestling culture is largely complex in that generations have passed down assumptions and opinions. These carry a significant amount of weight within the wrestling community, and it is something that was considered when establishing a new headgear. With aims to combat the stigmas surrounding cauliflower ear, the headgear was designed to please the athlete with its fit so that athletes will be more inclined to wear headgear when in practice. There are no political ramifications in association with this project.

The main goal of the project itself was to increase the wear of the headgear in practice for wrestlers. By increasing the amount of wear, the number of ear injuries should decrease, specifically the development of auricular hematomas. Since the design does not use any adhesive or coating, there should be minimal to no risk of skin irritation from chemicals. In a previous prototype design, the team had found few adhesives that were strong enough to hold the material, and were not considered irritants. The protective aims of this project and wrestling headgear itself support the betterment of athlete wellness in competition and practice, thus providing safer environments.

With manufacturability, the team aimed to create a design that is less complex than the current models. In creating a new device, the team wanted to create a device that mimicked the protective nature of the current headgear, but was simpler in design and more comfortable to wear. In doing so, the team was able to minimize the number of closures on the headgear, making a single adjustable strap the main method of attachment with the remainder of the straps containing elastic bands to allow for head size variation.

In keeping with objectives for a cost of around $40, a price breakdown of what the material and estimated manufacturing costs for a medium sized headgear are below:

TABLE 10: Cost Analysis

Headgear Component	Component Manufacturer	Original Cost/Original Amount	Amount Used	Total Cost per Headgear
Ear Cup	S.P. Richards Company, Georgia, USA	.019 $/in^2	188.5 in^2	$3.58
Nylon Straps	Country Brook Design, Alabama, USA	.012 $/in	23 in	$0.28
Elastic Straps	Singer, Tennessee, USA	.035 $/in	18 in	$0.63
Thread	Selric, New York, USA	.004 $/yard	Approx. 10 yards	$0.14
Cam	Strapworks, Oregon, USA	.90 $/cam	1 cam	$0.90
Labor		7.25 $/hr	1.67 hours	$12.11

This calculation leads to a total cost of $17.64 in production costs. This does not account for things like cost of equipment, but it is encouraging to our overall goal of a sale price below $40.

7. Final Design & Validation

The final design of the new preventative wrestling headgear was created in three different sizes denoted as small, medium and large. This was done by altering the length of the straps- the large had a top strap of 7in nylon and 1 in of elastic on each side, with back straps of 6in nylon with 1in elastic on each side. The nylon straps decreased by ½ in for the medium and 1 in for the small. The ear cups remained the same size. This eliminated the need for multiple straps that require adjustments in competition, alleviating the stresses of having to fit a new headgear during practice and workouts.

Figure 16: Final prototype on realistic human head

7.1: Impact Testing

Impact testing was done by dropping a 12lbs weight from a height of 1m onto both the market standard and our prototype. The max force was then calculated for each and compared via a two tailed t-test. This resulted in a p value of .115, allowing us to conclude there was not statistical difference between our prototype and the market standard, assuring us that we maintained market standard ear cushioning.

TABLE 11: Impact Testing

	Cliff Keen (N)	**Prototype (N)**
Test 1	2761	2901
Test 2	2761	2807
Test 3	2868	2839

7.2: Physical Testing

The final prototype was put through a series of test that allowed for the team to best understand the extent which is was comparable or exceeded the market standard. The first test was the implementation of the headgear in a practice setting. The team reconstructed a simple practice to an abridged version to complete multiple tests using both the market standard and the final prototype. Subjects were asked to complete an abridged practice using both the market standard and the teams design. In the course of twenty-five minute abridged workouts, each time the headgear was adjusted, the subject recorded a tally. This was completed with both the market standard as well as the team's headgear prototype- fit to the size of the individual completing the workout. As shown in Table 12 below, the prototype required significantly less adjustment than the market standard counterpart. The number of adjustments were denoted by a tally. The tallies were then compiled into the table for comparison. In a one tailed t-test, the p-value was 0.021 which proved that the prototype showed a statistically significant improvement compared to the Cliff Keen Signature headgear.

TABLE 12: Physical Testing

	Cliff Keen (# of adjustments)	**Prototype (# of adjustments)**
Session 1	9	4
Session 2	6	2
Session 3	7	5
Average	7.33+/- 1.52	3.66 +/- 1.52

7.3: Audibility Testing

To test audibility, subjects were asked to wear each of the headgear- Cliff Keen and the prototype- while completing an audibility test. The ambient noise level in the room during the test was approximately 45 decibels. A tone was played at 500 Hz using approximately 40% volume. The volume was decreased by 2% until the subject could no longer hear the sound. When this occurred, the sound was recorded.

TABLE 13: Audibility Test Results

	Cliff Keen	**Prototype**
Session 1	24%	16%
Session 2	24%	22%
Session 3	24%	20%
Average	24% +/- 0	19.33% +/- 3.05

The table shows that there was an increase in the subjects ability to hear with ambient noise while wearing the prototype than with the market standard headgear. Audibility was qualitatively described by subjects as improved by the final design as compared to the market standard.

TABLE 14: Objective Evaluation

Objective	Description	How Objective Was Met
Maintain market standard or better strap strength	The breaking point of the straps that secure the headgear to the head	Withstood greater than 1800 N in the suture retention test on the elastic and nylon strap
Maintain market standard or better ear cushioning	The ability of the headgear to absorb impact and twisting forces on the ear	Impact testing on showed so significant difference between prototype and market standard
Lower rate of adjustment compared to market standard	How much of practice is spent adjusting headgear per hour	Test subjects adjusted slightly less than half as often as market standard
Lower time to adjust headgear	How much of practice is spent adjusting headgear per hour	Subjects reported less time spent adjusting prototype than market standard
Improve comfort rating compared to market standard	Rating of comfort as given by subjects after wearing headgear	Unable to determine
Maintain or improve audibility compared to market standard	Ability to hear beeps and instructions given different levels of ambient noise	Subjects reported a statistically significant difference in audibility
Stay at a reasonable price given the current market	$60 is considered expensive for the current market, average is around $40	Analysis of materials and time shows a production cost of $17.64
Improve stated likelihood of wear compared to market standard	As determined by yes/no question asked of wrestlers having seen/used headgear	Coaches and athletes interviewed reported enthusiasm to wear new headgear
Improve aesthetic score compared to market value	Rating of aesthetics as given by wrestlers having seen/used headgear	Coaches and wrestlers reacted favorably to the new design

Following construction and testing of the final design, a final informal interview was conducted with the Worcester Polytechnic Institute head wrestling coach, the team was given positive feedback. The design was well received and supported to be better than the current standard with regard to comfort and usability.

8. Conclusions & Recommendations

In final evaluations of the prototype, the improvements in overall comfort and audibility fit the needs of athletes in practice, and further increase the likelihood of wear when not required. Further recommendations include more human subject testing with more vigorous activities like live wrestling and high intensity workouts to better gage the functionality of the headgear. In addition, testing to evaluate the longevity of the gear in use would provide deeper insight and comparisons with the current market standard.

Looking towards the future, there are several issues with headgear that can still be addressed. The while many people in the survey we conducted said that they would be willing to wear headgear if the problems with it were addressed, 17% of respondents said that they would not wear headgear even if all of them problems were fixed. This indicates a culture that glorifies certain injuries and minimizes the importance of wearing protective equipment. This is also clear from a few written responses of the survey. When answering a question about what their complaints are about current headgear, one respondent said “That it protects my ears” and another said “... it is about to become irrelevant because cauliflower ear is seen as more of a positive…” This is not something that new types of headgear can fix, rather requires a shift in the culture perpetuated by years of wrestling stigmas.

Other aspects of the headgear that could be addressed from an engineering perspective would be the requirement of hair coverings for individuals with long hair in matches. Much like the mentality surrounding headgear, the hair coverings are ill-fitting and often make the implementation of headgear more difficult. A future consideration would be to create an integrated hair-covering to best include those who require said coverings per NCAA guidelines.

In regards to further work with our prototype, further testing with our prototype is necessary for a completely accurate assessment of how well it meets our objectives, as well as to suss out any problems that may not have been spotted in the limited testing our team has been able to accomplish. Further, it is critical to get the headgear on athletes for wear in practice for long period of time, as the current collected data is limiting to the full extent of the prototypes success. In addition to this, the team intends on completing the steps to patent the novel aspects of the design with the hopes of bringing the design to wholesale players in the wrestling world like Cliff Keen and Adidas. In doing so, the team plans to look into grants to travel and pursue further outlets for marketing and supporting growth for the device on the market after the completion of the project.

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Appendix A: NCAA Divisional Committees

Division	Title	Name & Institution	Conference	Term Expiration
FBS	Head Wrestling Coach	John W. Smith Oklahoma State University	Big 12 Conference	AUG 2022
FCS	Assistant Athletic Director	Matt Valenti University of Pennsylvania	The Ivy League	AUG 2020
FCS	Senior Associate Director of Athletics	Jack Maughan North Dakota State University	The Summit League	AUG 2021
DI	Senior Associate Athletics Director	Jason Coomer Southern Illinois University Edwardsville	Ohio Valley Conference	AUG 2019
II	Head Wrestling Coach	Cy Wainwright Newberry College	South Atlantic Conference	AUG 2021
II	Head Wrestling Coach	Jason Warthan University of Indianapolis	Great Lakes Valley Conference	AUG 2019
III	Head Wrestling coach	Brad Bruhn State University of New York at Cortland	State University of New York Athletic Conference	AUG 2022
III	Head Wrestling coach	Lonnie Morris Johnson & Wales University (Providence)	Great Northeast Athletic Conference	AUG 2020

*Eligible for reappointment

NCAA Wrestling Rules Committee

Division	Title	Name & Institution	Conference	Term Expiration
FBS	Head Wrestling Coach	Brian Smith University of Missouri, Columbia	Southeastern Conference	AUG 2019
FBS	Head Wrestling Coach	Tom Ryan The Ohio State University	Big Ten Conference	AUG 2019
FBS	Sr. Associate AD for Internal Operations	Phil Wille University of Wyoming	Mountain West Conference	AUG 2020
FCS	Athletic Director	J. Andrew Noel, Jr. Cornell University	The Ivy League	AUG 2022
DI	Associate AD for External Relations	Karen Langston California State University, Bakersfield	Western Athletic Conference	AUG 2021

*Eligible for reappointment

Division I Wrestling Committee

Division	Region	Title	Name & Institution	Conference	Term Expiration
II	WEST INDEPENDENTS	AD	Miles Van Hee Western State Colorado University	Rocky Mountain Athletic Conference	AUG 2022
II	CENTRAL INDEPENDENTS	Associate AD/SWA	Ann Traphagen Augustana University (South Dakota)	Northern Sun Intercollegiate Conference	AUG 2019*
II	EAST INDEPENDENTS	Head Wrestling Coach	Brian Tucker Seton Hill University	Pennsylvania State Athletic Conference	AUG 2021
II	MIDWEST INDEPENDENTS	Head Wrestling Coach	Kelly Revells Limestone College	Conference Carolinas	AUG 2021
II	MIDWEST INDEPENDENTS	SWA, Associate Director of Athletics	Jackie Paquette University of Indianapolis	Great Lakes Valley Conference	AUG 2020

*Eligible for reappointment

Division II Wrestling Committee

Division	Title	Name & Institution	Conference	Term Expiration
III	AD	Jeff Swenson Augsburg University	Minnesota Intercollegiate Athletic Conference	AUG 2020
III	AD, Director of Athletics & Head Wr. Coach	Eric Van Kley Central College (Iowa)	American Rivers Conference	AUG 2020
III	Head Wrestling Coach	Eric Walker Elizabethtown College	Landmark Conference	AUG 2022
III	Head Wrestling Coach	Roger W. Crebs Lycoming College	Middle Atlantic Conferences	AUG 2019
III	Head Wrestling Coach	Ron Beaschler Ohio Northern University	Ohio Athletic Conference	AUG 2021
III	Head Wrestling Coach	Scott Honecker Williams College	New England Small College Athletic Conference	AUG 2021

*Eligible for reappointment

Division III Wrestling Committee

Appendix B: Survey

Hello, we are a team of Worcester Polytechnic Institute students working with the Biomedical Engineering Department on our Major Qualifying Project titled: Preventative Wrestler Headgear. The purpose of this survey is to gather preliminary input on improvements that the team could make on headgear. You do not have to answer questions that you do not feel comfortable answering.

Below is a draft of the questions the team plans on implementing in surveys with both coaches and student-athletes:

1. How many years have you been involved in wrestling?
    a. Less than 1
    b. 1-4
    c. 5-8
    d. Greater than 8
2. At what level(s) have you participated in the sport?
    a. High School
    b. Collegiate
    c. Professional
3. What institution do you wrestle for?
4. Is headgear required in your practices?
    a. Yes
    b. No
5. How often do you wear headgear in practices?
    a. All of the time (Every practice)
    b. Most of the time (4 out of every 5 practices)
    c. Some of the time (3 out of every 5 practices)
    d. Occasionally (2 out of every 5 practices)
    e. Rarely (1 or fewer practices out of five)
6. Have you ever experienced auricular hematoma (cauliflower ear)?
    a. Never
    b. Once or twice
    c. Three to five times
    d. More than five times
7. If you responded once or more to the previous question, how did you treat the cauliflower ear?
8. Have you ever had a head injury participating in your sport of wrestling. If so, could you describe the scenario of how you were injured and what injury actually occurred.
9. What are the main issues you have with headgear?

10. Please fill in the blanks: If headgear had _____________ or did not have _________________ I would be more likely to wear it.

Appendix C: GANTT Chart

Appendix D: Testing Protocols

Audibility:
Vary decibel level (50-90) not exceeding 100 as that can cause damage
Average decibel level at NCAA National Championships: 89.4 decibels
Compare with the levels listed for other sporting events
https://www.starkey.com/blog/2015/08/loudest-sporting-events

Test Procedures ASTM F1446

12.1 Reference Marking—A reference headform mounted with the basic plane horizontal shall be used for reference marking. The helmet to be marked shall be placed on a reference headform the same size as the test headform to be used. The helmet shall be centered laterally and seated firmly on the reference headform with the preload ballast on the helmet, then positioned according to the helmet position index (HPI). Ensure that the brow is parallel to the basic plane. The test line shall be drawn on the helmet as required by the individual performance standards. The center of impact sites shall be selected at any point on the helmet on or above the test line.
12.2 Configuration—The helmet shall be constructed to reduce or minimize injury to that portion of the head that is within an area above the test line and to remain on the wearer's head during impact.
12.3 Materials—Materials known to cause skin irritation or disease cannot be used in the helmet. Lining materials, if used, may be detachable for washing. If hydrocarbons, cleaning fluids, paints, transfers, or other additions will affect the helmet adversely, a warning shall be provided.
12.4 Labeling—Each helmet shall contain labels with at least the following information, using terms and symbols commonly known and easily visible to users. The label(s) should be likely to remain on the helmet and legible throughout the intended design life of the helmet.
12.4.1 The number of the standard specification which the manufacturer certifies that it meets, including the two-digit version year appended to the number.
12.4.2 Model designation.
12.4.3 Name of manufacturer.
12.4.4 Month and year of manufacture.
12.4.5 A label that warns the user that no helmet can protect against all possible impacts and that for maximum protection the helmet must be fitted and attached properly to the wearer's head in accordance with the manufacturer's fitting instructions.
12.4.6 A label that warns the user that the helmet may, after receiving an impact, be damaged to the point that it is no longer adequate to protect the head against further impacts, and that this damage may not be visible to the user. This label should also state that a helmet that has sustained an impact should be returned to the manufacturer for competent inspection or be destroyed and replaced.

12.4.7 A label that warns the user that the helmet can be damaged by contact with common substances (for example, certain solvents, cleaners, hair tonics, etc.) and that this damage may or may not be visible to the user. This label should also list any recommended cleaning agents or procedures, or both.
12.4.8 Any other warnings, cautions, or instructions specified in the individual standard specification.
12.4.9 Each helmet shall have accompanying fitting and positioning instructions including graphic representation of proper positioning.
12.5 Projections:
12.5.1 Interior Projections—Any internal rigid projections that can contact the wearer's head during impact shall be protected by some means of cushioning or force spreading. Visually inspect a single helmet from the set for the presence of any interior projections. Verify that if projections are present they are protected.
12.6 Vision:
12.6.1 Peripheral Vision—The helmet to be tested shall be placed on a reference headform the same size as the test headform to be used. The helmet shall be centered laterally and seated firmly on the reference headform with the preload ballast on the helmet, then positioned according to the HPI. Ensure that the brow is parallel to the basic plane. Measure the peripheral vision on a single sample of each helmet set. The peripheral vision is measured horizontally to each side of the midsagittal plane through Point K (see Fig. 13). The vision shall be unobstructed through an angle on either side of the midsagittal plane from Point K as identified in the individual performance standards.
12.7 Retention System—The retention system shall be designed and constructed to meet the requirements of this section and any other requirements called for in the individual performance standards.
12.7.1 Dynamic Strength Retention Test:
12.7.1.1 Summary of Test Method—A drop weight delivers an impact load to the retention system. The drop weight, drop height, and allowable elongation are specified in the individual performance standards. See Fig. 5 for a typical test apparatus setup.
12.7.1.2 Procedure—Place the helmet on the appropriate size reference headform and adjust fit system according to manufacturer instructions. Adjust to the HPI. Fasten the strap of the retention system under the headform mandible, secure the buckle and adjust the retention system according to the manufacturer's instructions. If there are separate front and rear straps, they must be adjusted to remove any slack. Then place the helmet on the appropriate size test headform and adjust to the HPI provided by the manufacturer. Fasten the strap of the retention system under the mandible fixture so that no part of the retention fastening system shall contact the mandible fixture prior to release of the drop mass. This shall be achieved by either loosening or tightening the retention system, if necessary. For helmets incorporating separate front and rear straps, these shall not be readjusted. The entire dynamic test apparatus hangs loosely restrained from

non-vertical movement on the retention system. Raise the drop weight to the drop height and allow the drop weight to fall and impact the rigid stop. Electronically measure elongation of the retention system in terms of vertical displacement of the dynamic test apparatus measured between the before drop position and the maximum dynamic extension. The allowable displacement is specified in the performance standard.

12.7.2 Roll-Off:

12.7.2.1 Summary of Test Method—A drop weight delivers an impact load to the helmet in a manner to roll the helmet off the headform. The drop weight and drop height are specified in the individual performance standards. The test stand used for helmet roll-off (stability) testing is shown in Fig. 4. Unless specified in the individual performance standards, the helmet must not be ejected or excessively displaced on the headform. The helmet will be considered to be excessively displaced if those parts of the coronal plane that were covered by the helmet before the test become exposed after the test in either orientation.

12.7.2.2 Procedure—The helmet shall be placed on the appropriate size reference headform and adjusted to the HPI provided by the manufacturer. The headform is mounted face down for the first sequence and face up for the second sequence. These tests shall be described as "Face Up" and "Face Down" to avoid confusion. The helmet retention and fit systems shall then be adjusted according to the instructions furnished by the manufacturer. The guide rod and drop weight are similar to those in the retention strength test minus the mandible fixture. The guide rod can be restrained from non-vertical motion as long as it remains plumb with the hook and strap. The roll-off hook with attached cable is hooked to the upper center of the helmet and the cable is directed over the helmet along the midsagittal plane and then attached to the guide rod. Raise the drop weight to the drop height and allow the drop weight to fall and impact the rigid stop. No pad shall be used between the drop weight and the rigid stop. The drop weight and drop height are determined by the individual performance standard.

12.8 Impact Attenuation—The helmet shall be designed and constructed to meet the requirements of this section and any other requirements called for in the individual performance standards.

12.8.1 Summary of Test Method—Impact attenuation is determined by measuring the acceleration of the test headform during impact. Acceleration is measured by a uniaxial accelerometer. The helmet and headform are dropped in a guided free fall, using a wire or rail guided apparatus (see Fig. 6), onto an anvil fixed to a rigid base. The required impact velocities, impact sites, and anvils are identified in the individual performance standards. Maximum allowable accelerations are specified in the individual performance standards. Other acceptance criteria may be defined in the individual performance standards.

12.8.2 Procedure:

12.8.2.1 Instrumentation Check—The system instrumentation shall be checked before and after each series of tests as identified in 9.2.

12.8.2.2 Impact Sites and Anvils—Each helmet shall be impacted at four sites, unless identified in the individual performance standards. The center of impact shall be at any point on or above the test line and at least one fifth of the maximum circumference of the helmet from any prior impact center. As many different anvils (called for in the individual performance standards) as possible shall be used on each helmet. All anvils called for in the individual performance standards shall be used within a given test set of helmets. Any anvil may be used at any site (unless otherwise noted by the individual performance standards). Additional impact sites may be designated by the individual performance standards.
12.8.2.3 Velocity—The impact velocities and theoretical drop heights (assuming 9.807-m/s^2 acceleration rate) for impact testing are specified in the individual performance standards. Impact velocity shall be measured during the last 40 mm of free fall for each test and shall be within the limits specified in the individual performance standards.
12.8.2.4 Helmet Impact Testing—Prior to each test, position the helmet on the test headform as identified on the reference headform and adjusted to the HPI provided by the manufacturer. The helmet shall be secured so that it does not shift position prior to impact. During impact testing the retention system shall be secured in a manner that does not interfere with free fall or impact. Install the required anvil. Adjust the headform for an impact on the helmet at the identified site. Raise the drop assembly, with helmet, to the test drop height, measured from the lowest point of the helmet to the surface of the anvil, and allow the assembly to impact the anvil under a guided condition. Record the impact velocity and acceleration time history. Repeat this sequence until the required impacts are performed.

The Bluehill method for tensile testing was prepared. Specimen properties were set to a rectangular geometry and physical measurements were set to record data for time(secs), extension(mm), load(N), tensile strain (Extension), tensile extension(mm), and tensile stress(MPa). The graph was set to have an x-axis of time(secs) and a double y-axis of load(N) and extension(mm) and the test was set to end when the load was back at 0N, which occured when the specimen was broken. Before beginning the tests, tare loads of approximately 5 N were applied to each sample section to put pressure on the sample and ensure the specimens were stable and would not slip. The displacement was zeroed and a digital caliper with a ±0.01 mm accuracy was used to measure the width and thickness of each specimen section as well as the length between the two grips.

The pre-calculations for the specimen were evaluated using the UTS of each material to determine the maximum force. Since the max force of each sample did not exceed the max load cell capacity of the Instron (2000N) and was greater than 1% of the load cell's full range (20N), the sample was able to be tested using the machine.

$$F_{max} = UTS * \frac{4I}{\ell r_o}$$

For In Practice Wear Testing: (based on a typical 1 hour practice in season)
Participants will wear either the teams headgear or their own or none and the team will get a control and variant opinion on the headgear

5:30-5:45 **Warm Up**

Circle Run + Gymnastics - 10 min

Quick TD SetUp Drill warm up - 5 min

5:45-5:55 **HeadPositionHandFight and Motion Drilling**

5:55-6:05 **Top/Bottom work**

5:00 Top

5:00 Bottom

6:05-6:15 **Easy In - Hard Out Take Downs**

10 min - 5, 6, 7 o'clock

- 11/1 o'clock

- Fav #1 GoTo TD

- Defend/CounterAttack To Score

6:15-6:25 **Live** 3-man groups

TD Winner Stays - 4 mins

Top/Bottom - 3 mins *Rotation*

TD Winner Stays -3 mins