Blunt Impact Performance Evaluation of Helmet Lining Systems for Military and Recreational Use

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Abstract:

With the increasing problem in collegiate athletes experiencing injuries to the brain, different helmet liners where put to the test to see which liner provided athletes the greatest protection under specific conditions.

This senior project evaluates five different liners in football helmets. Each of the helmet liners were tested at three different temperatures: hot, cold, and ambient. Each helmet had seven different impact locations which were put to the test. The project was designed to be used to test ACH military combat liners as well. Due to shipping bottle necks the ACH combat liners have been left to future Cal Poly students to test. This report includes the data generated from testing which will be used to determine which football helmet liner provides the greatest protection.

The proposed procedure has been developed and reviewed by Dr. Lou Tornatzky and Dr. Jay Singh. The resulting data will conclude which helmet liner is recommended for the Cal Poly Football team.

Acknowledgements:

This project would not have been able to be completed if it were not from the help of Mr. Lou Tornatzky our faculty advisor, Mr. Jay Singh our technical advisor, Evan Cernokus and David Guadagnini. The materials and testing equipment were provided by Lansmont, the Cal Poly Football team, and the US Navy. Our thanks and gratitude go out to all those who helped make this project happen.

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Project Diary

So far in this quarter, our group has been continuously working on making more progress on our project as well as making any corrections needed from the first quarter of this project. Our literature review section has been revised and we have revised our testing procedures that we will follow. Our testing apparatus is all complete but we are still waiting on shipment of the headform with the mounted accelerometer in it. We have obtained six Army ACH helmets to start testing with. Our six liners have been ordered and we are waiting on shipment. Tables and charts have been made for us to help streamline our testing. Machine and program training will take place within the next week by either Evan or David. Once the liners have been received our testing will begin and take about two weeks to complete.

Our group has faced some problems in the obtaining of materials that have set us back. Since we are still waiting on one more piece for our testing machine, we have not encountered any problems with our testing method and experimental design. We originally planned for the machine to be complete by the end of the third week of this winter quarter but plans have been delayed due to the transportation of the remaining parts. We are also debating on if six helmets will be sufficient to complete all testing with each of the liners at the three different temperatures. We are still contacting outside sources to find more helmets if it is required. We have established contact with Camp Roberts Central Issuing Facility (CIF). They do issuing of equipment and uniforms for the National Guard and we are hoping to obtain some helmets from them. We have also established contact with Vandenberg Air Force Base Lompoc at the Defense Reutilization and Marketing Organization (DRMO). They handle all the old equipment units and we are hoping to get a few before they are discarded. Current standard issue lining systems will also have to be acquired to be tested as a benchmark for the other experimental liners. With the few delays we are continuing to experience, we must reevaluate our project timeline and the tasks that need to be accomplished within it.

Through our experience with this project thus far, we have learned that everything doesn't go as planned. For the remainder of the project we must account for any possible setbacks that may occur in the future and figure out how we will deal with them if they do arise. Much of the work we have done involves prior research and background information to help us later in the project. The remaining portion of this project will involve much more time spent on testing and data analysis. Once the sufficient material is gathered our testing procedures and methods can begin.

There is always room for improvements that could make the remainder of this project run more smoothly. With everyone's busy schedules conflicting with each other's, it is difficult to communicate and meet up with each other on a regular basis. Regardless of this problem, we can improve on keeping up communications with each other as well as our technical advisor through various forms of communication. We have found it extremely beneficial to meet during our assigned time and have been very productive via Google docs. We are all able to edit and collaborate at the same time in case any of us have any issues that need to be addressed. As stated before, we should also prepare for potential problems that may arise. There are also new risks that can occur that were not identifiable before we had the information we do now that are more specific. Since it has taken so long to deliver the machine parts if a part breaks during testing, there will be considerable downtime. Our group also does have enough ACH helmets for testing. Our first route is to look for donations from ROTC or any branches of the armed forces. If we do not gather enough helmets then we will have to search for funds to purchase additional units.

Once the machine is up and running and our testing materials are available, we will create a testing schedule so that they will be run by the group as a whole as well as by single individuals. We would like testing to be completed all at once but depending on the availability of test materials this may be delayed. Below is a list of tasks and an estimated completion date.

Introduction

Problem Statement:

The current head protection that the military is using is the Advanced Combat Helmet (ACH) given to every infantry personnel. These combat helmets were designed primarily to protect against ballistic impact but there has been more interest in the protection against blunt force impacts. There exist three main threats in a military environment; motor vehicle accidents, trip and fall accidents, and the airborne environment. These problems largely exist during peacetime but still pose as potential threats. The protection against blunt force impact depends primarily on the dissipation of energy through the helmet than through the person's head. We are performing these tests to determine the best cushioning material protecting against blunt force impact. This cushioning testing and design will be used by all branches of military as well as all football players.

Needs:

The basis of a protective device is to protect the user from potential risks and be able to guard against that risk. In the case of helmets this protection is imperative to the individual's risk against disability as well as survivability. During peacetime, the majority of head injuries were causes from accidental exposure to blunt force while in wartime there was an additional threat of penetrating head trauma from high speed projectiles. Little attention was paid to protecting the head from blunt force impacts. The requirements of an improved helmet would include better protection against blunt force trauma, protection against ballistic penetration, maintain durability and service time, improve the comfort for extended periods of operation time, and cost effectiveness. The importance level of these needs is shown in the table below.

Table 1

Need	Importance Rating
Blunt Force Protection	1
Ballistic Protection	2
Durability	3
Extended Comfort	4
Cost Effective	5

Background or Related Work:

When selecting this project, the main focus was on helmets used in military applications. Our group decided to include the addition of athletic football helmets since both of these products have similar protection requirements against blunt force impacts. In this sense, many of the previous tests that have been performed on one helmet can apply to the other. When looking for background literature and related work we will be looking for information on both helmets. Related to athletic football helmets, The National Operating Committee on Standards for Athletic Equipment (NOCSAE) has created a standard method for performing impact tests as well as a list of necessary performance requirements. A previous research was done by the Army Aeromedical Research Lab in Fort Rucker Alabama in 2005. The research lab tested blunt force impact levels on ACH helmets in three different environmental scenarios as well as in seven different angles.

Objectives:

During this project, we will be testing various cushioning materials at different angles and evaluating the level of protection that each one provides against blunt force impacts. The seven different locations are as following: front, back, left side, right side, lower left nape, lower right nape and the crown. We will be testing the helmets at three different temperatures. The temperatures are as following: Ambient 70± 5°, Hot 130 ± 5°, and cold 14 ± 5 °. Through analysis and evaluation we will settle on a final recommendation regarding the most effective material against blunt force impacts as well as increased protection performance for the user.

Contribution:

This cushioning material research will contribute to a very wide audience. We are working with the US Navy and our teachers in hopes of finding a solution for the current problem. Since we are testing military and football helmets, our audience includes all branches of the military, as well as every pop warner, high school, collegiate, and professional football teams. Aside from these two large groups, this project will also aid to any application requiring headgear that delivers protection against blunt force impacts.

Scope of Project:

The scope of our project will include the testing of cushioning materials in military and football helmets. The testing will be done on one drop test apparatus. Since there is a vast selection of materials to choose from, we will limit ourselves to testing up to five different materials that we feel will have the best outcome. We will be using the same helmets but we will change the liners inside them. Testing the different liners at different temperatures and at seven different spots will give us enough information to analyze and come up with the best protective gear depending on the circumstances. After completion of testing, a report on the characteristics of each cushioning will be submitted as well as a recommendation for further improvement.

Literature Review

The project we have decided to do is blunt impact performance evaluations of helmet lining systems for military use as well as football helmets. We are doing this in order to reduce the number of concussions that occurs as well as improve the comfort of the user over extended periods of time. This project is very valuable to the success of our military and players today. Recently there were over 500,000 recalls of military helmets due to performance issues. Previously the main focus for the advanced combat helmets was ballistic and penetration testing. Now that the ballistic performance is satisfactory, the focus is shifting to blunt force testing. There are many instances in which a soldier or a football player will have a blunt force impact so we are intending to find the most suitable liners that will protect our players/soldiers within a realistic price range. The importance of our literature search is to find relevant projects or research done on the previous performance of these helmets. We want to learn why our helmets have developed to where they are now and also learn from the mistakes that past project have proven. Researching past literature on this topic will be a great tool for learning the scope of what problems we may be dealing with. In this section we are going to show several cases and examples in which the military and football helmets have been improved and how our findings and results will continue to enhance the protection and safety of our helmets users.

Combat Helmets

In 2005, the Army Aeromedical research lab in Fort Rucker, Alabama did a test in order to find the critical points in which a blow to the head can cause concussions. For our testing we are going to be testing each helmet at an impact velocity of 14.14 (±3%) feet per second at seven different locations (front, back, left side, right side, lower left nape, lower right nape and the crown.) We found from their study that these seven locations take the brunt of the force when impacted. The front, back and sides are tested for when a soldier head comes in contact with the ground for any reason. The napes and crown of the helmet are tested for objects and debris that may come in contact with the soldier through the air. (McEntire) We will be using a guide wire free fall drop tower, five padding systems, and a tri-axial piezoelectric linear accelerometer. We need our test to conduct which of these areas is the most susceptible to concussion so that we can enforce a padding system catered to that area. The padding will be rested according to the

Federal Motor Vehicles Safety Standard (FMVSS) 218 (US DOT). The testing that has already been done was tested at two impact velocities, three environmental temperatures, and seven impact sites with two successive impacts. (All of which are unknown)

> "The performance of each was characterized by the transmitted acceleration measured within a standard head form and compared against the recommended threshold for mean and maximum acceleration."(McEntire).

We believe that our research and testing can help improve protection from blunt impacts. It will test the latest experimental padding materials to be evaluated for the ability to withstand a blunt force in these seven traumatic areas.

Even with all the testing in the world nothing can compare to the test of a soldier or a football player actually wearing the helmet. The moment of truth is when the helmets are actually put to the test. Based on the article, "How Satisfied Are soldiers with Their Ballistic Helmets A Comparison of Soldiers," we were able to learn about the different factors that are considered during helmet design. Comfort, weight, fit, and maintainability, and protection are just a few factors that affects soldier's decisions in helmet use. "Rigorous research about soldiers' real-life experiences with helmets is critical to assessing a helmet's overall protective efficacy." (Ivins, Brian J.; Schwab, Karen A.; Crowley, John S.; McEntire, B. Joseph; Trumble, Christopher C.; Brown, Fred H.; Warden, Deborah L 586-591) The study compared soldiers' satisfaction and problem experience with the Advanced Combat Helmets and the Personal Armor System for Ground Troops Helmet (PASGT). The data was obtained from soldiers at Fort Bragg North Carolina. Ninety percent of ACH users were satisfied overall with their helmet while only nine and a half percent were satisfied with their PASGT helmets. The study showed how most soldiers' preferences was for the ACH rather than the PASGT, however we are looking for one hundred percent satisfaction and protection. This leads us to test several different liners for the ACH helmets in order to find one that passes our rigorous test and maintains comfort for our soldier. We want to arrange a comfort test with each of our liners on five different test subjects. We want to couple those results with our accelerometer results in order to successfully evaluate each liner entirely.

In October 2003 there was another study in Fort Bragg, North Carolina on Traumatic Brain Injury (TBI) frequency of the 2,337 active duty soldiers. The results were gathered from 1999-2000 as part of a larger ongoing Institutional Review Board. "The results were that approximately twenty three percent of all soldiers surveyed reported sustaining a TBI after joining the Army." (Ivins 617-621) After all the studies were concluded it was realized that parachuting appears to be a risk factor for mild TBI in the US army. It was also concluded that those with a history of TBI before the Army have a higher risk of sustaining additional TBI while serving in the army. We need to design helmets that are keeping our parachuters safe. This study shows the underlying problems of TBI in our military and we need to find a valuable solution. The temperature at which these men are jumping can have a major affect. Most jumps during active duty are during the night hours where temperatures can reach the low 20's. We want to see if the temperature of the helmets and padding changes the characteristics and benefits of the padding system.

In June 2006, the House of Armed Services Committee requested that the Department of Defense conduct non-ballistic blast and blunt force impact testing on Marine Lightweight Helmets (LWH) and on the Army's ACH helmets. In accordance to blunt impact testing, the DoD does not have any unique method for testing this so they pulled procedure done by the U.S. DoT and the U.S. Army Aeromedical Research Laboratory (USAARL). Our study will loosely follow the same procedures and established testing values from the USARRL study. For example our established acceleration threshold will be 150-g mean peak acceleration and our impact velocity will be at 14.14 feet per second. The experiment tested four different lining systems that were out on the market at the time. They were all tested at each of the three different temperatures and the average and peak G's were recorded for each liner. In the conclusion of this experiment, none of the liners they tested met the performance requirements with an impact velocity of 14.14 ft/s. All of them exceeded the mean peak acceleration of 150 G. This study shows that there is still a need for a new lining system that will meet these protection expectations. Since this study, there have been new innovative materials that could possibly meet these requirements.

In a March 2011 patent by the Mine Safety Appliances Company a new design for the inserts of the protective helmets was created. Previously the protective helmets for the military use an insert consisting of webbing that sat on the soldiers head. The outer shell of the helmet is actually raised up from the head separating it from the inside liner. This allows ventilation throughout out the helmet too keep body temperature down because some of these helmets will be used in very high temperature situations. The helmets suspension design does cause undesirable pressure points to the users head. The company decided that they should put some comfort padding inside of the helmets so that they could have increased comfort as well as the ventilation the soldiers desire. The patent was a design to incorporate closed cell polymer beads encased in a nylon type lining so that is still offers the breath-ability yet it will also allow the disbursement of pressure through the impact point. This design will be very beneficial for the soldiers because this will decrease the symptoms that occur from concussion such as dizziness, nausea and unconsciousness. For our project we are not only focused on how well we can prevent this symptoms, we also need to be able to prevent these symptoms while our helmets are under strenuous conditions such as wetness, heat or even frozen. All of these factors will have a major contribution to how the liners of the helmets react upon the impact. The comfort must be there so the soldiers will where it yet let in enough ventilation to keep them cool.

Football Helmets:

There is a common problem arising in the NFL as well today having to do with concussions. The same issues arise when talking about football helmets as they do when talking about combat helmets. The impact that occurs in a football collision can be measured up to 1600 lbs of force which is applied to the player's brain. Temperature is a major factor in the collision as well. If a player is playing in a cold environment the padding in the helmet is going to have a different affect on the safety of the player then when the helmet is in a tropical environment because cold air is actually heavier. "National Football League player concussions occur at an impact velocity of 9.3 +/- 1.9 m/s (20.8 +/- 4.2 mph) oblique on the face mask, side, and back of the helmet. There is a dire need for new testing procedures to evaluate helmet performance for violent impacts causing concussion." We are going to see if air pressure needs to be changed according to the temperature in order to fully protect the player. We feel that this is a key point of focus because the numbers of concussion have risen exponentially over the last several years. It is stated that ex- players ages 30-50 years old are 19 times more likely to contract a memory loss disorder or illness. This is a statistic that needs to be addressed as soon as possible for the safety and wellbeing of the players. There is experimentation's with material such as carbon fiber and Kevlar in order to absorb some of the shock that is generated. Under no conditions should cost be a factor in protecting individuals with these helmets. NOCSAE is currently raising their standards in order to better serve for protection. Instead of testing at 7.4 and 9.3 m/s which is the speed at which a concussion can occur, they chose to raise the speed to 11.2 m/s in which the padding bottoms out and head trauma increases rapidly. Helmets are now being engineered to cater to more of a F1 racing style helmet so that it may further prevent concussions. We need to see at what point the helmets are no longer functioning at peak performance, because this is when players become more at risk and prone to concussions.

There was a study on twenty five helmet impacts to test the impacts causing concussion in professional football players. They were simulated in laboratory tests to determine the collision. The study focused on the bio-mechanics of the concussion in the struck player. "Twenty-five helmet impacts were reconstructed using Hybrid III dummies. Head impact velocity, direction, and helmet kinematics-matched game video. Translational and rotational accelerations were measured in both players' heads; 6-axis upper neck responses were measured in all striking and five struck players" (Viano 313-328) Later on a model was developed of the helmet impact to study neck strength and other head responses. The results were as following, "The impact response of the concussed player's head includes peak accelerations of 94 ± 28 *g* and 6432 ± 1813 r/s2, and velocity changes of 7.2 ± 1.8 m/s and 34.8 ± 15.2 r/s. Near the end of impact (10 ms), head movement is only 20.2 ± 6.8 mm and 6.9 ± 2.5 degrees. After impact, there is rapid head displacement involving a fourfold increase to 87.6 ± 21.2 mm and 29.9 ± 9.5 degrees with neck tension and bending at 20 ms. Impacts to the front of the helmet, the source of the majority of National Football League concussions, cause rotation primarily around the *z* axis (superior-inferior axis) because the force is forward of the neck centerline. This twists the head to the right or left an average of 17.6 ± 12.7 degrees, causing a moment of 17.7 ± 3.3 Nm and neck tension of 1704 ± 432 N at 20 ms. We will be using a tri-axial accelerometer so that we can get data in the X, Y and Z-axis. This data will allow us to correlate our results in to real if applications by axis. The head injury criterion correlates with concussion risk and is proportional to ΔV4/d1.5 for half-sine acceleration. Stronger necks reduce head acceleration, ΔV, and displacement." (Viano 313-328) These results show us that concussions can occur from all sides and angles and we must be prepared for those. Not is on only the front and back important to concussion prevention. (Viano 313-328) Football as a sport will never go away so it is important to find the best technology to protect our athletes.

Based on the study by Lawrence Lewis MD, Rosanne Naunheim MD, John Standeven PhD, Carl Lauryssen MD, Chris Richter MD and Brian Jeffords MD "Do Football Helmets Reduce Acceleration of Impact in Blunt Head Injuries," the objective was to measure the effectiveness of a regulation football helmet to reduce the acceleration of impact for both low- and moderate- force impacts. The method was as following "An experimental paired study design was used. Male volunteers between 16 and 30 years of age headed soccer balls traveling approximately 35 miles per hour bareheaded and with a helmet. An intraoral accelerometer worn inside a plastic mouthpiece measured acceleration of the head. The helmet also had an accelerometer placed inside the padding. For more forceful impacts, cadaver heads, both with and without helmets, were instrumented with intraoral (IO) and intracranial (IC) accelerometers and struck with a pendulum device. Simultaneous IO and IC accelerations were measured and compared between helmeted and unhelmeted cadaver heads. The main outcome was mean peak acceleration of the head and/or brain associated with low- and moderate-force impacts with and without protective headgear." (Lewis 604-609) This is a very good way of testing because it is real life testing on people who can give feedback on comfort and what they were feeling depending on the helmet. We plan to incorporate such testing in our project to get actual feedback on comfort and pain levels. Depending on the different liners we can have our test subjects test them with real life impacts. We will ask them which felt best and which provided the greatest comfort. We can also attach the accelerometer to the helmet as they did in the study to record data based on the impact. The results of the study done by Mr. Lewis and his colleagues were as following, "Mean peak Gs, measured by the mouthpiece accelerometer, were significantly reduced when the participants heading soccer balls were wearing a helmet (7.7 Gs with vs 19.2 Gs without, $p = 0.01$). Wearing a helmet also significantly lowered the peak Gs measured intraorally and intracranially in cadavers subjected to moderate-force pendulum impacts: 28.7 Gs with vs 62.6 Gs without, $p < 0.001$; and 56.4 Gs with vs 81.6 Gs without, $p < 0.001$, respectively." (Lewis 604-609) More importantly than the numbers that resulted from the tests was the ability to ask the test subjects feedback on how they felt. It was concluded that "A regulation football helmet substantially reduced the peak Gs associated with "heading" a soccer ball traveling at moderately high velocities. A helmet was also effective in reducing the peak acceleration both intraorally and intracranially for impacts significantly more forceful than heading a soccer ball.” (Lewis 604-609) This study really opened our eyes to the different types of testing that we can do in calculating data. With the reduction of G’s due to these helmets, we need to figure out where this dispersion of energy is going. Using the accelerometers for our test will correlate perfectly when we start changing air pressure within the football helmet liners. This is an example of thinking outside the box for us rather than solely relying on simulated test experiments. Testing with soccer balls is only just a start to the different impacts we can be testing.

Based on the literature review of the previous works and the historical background on blunt impact performance evaluations, we have learned a lot and know the necessary changes needed to make in testing to come up with better and more accurate results. The limitations to the studies that we have researched were that a lot of the studies required us to buy the article in order to see the full study. The information we got from these cases and studies allowed us to set up testing procedures to account for all the variable and situations one could possibly encounter in a live situation. Our project is going to be adding a few more variables in the padding of the helmets and the temperature variable so that the wide range of users will have the correct gear for their situation and climate. We will also be doing a lot less focus on cost effective and more on durability and protection. The importance level of the previous studies needs is shown in the table below.

Table 2

Need	Importance Rating
Blunt Force Protection	1
Extended Comfort	2
Cost Effective	3
Ballistic Protection	4
Durability	5

Solution

Alternative Solutions:

The current head protection that the military is using is the Advanced Combat Helmet (ACH) given to every infantry personnel. These combat helmets were designed primarily to protect against ballistic impact but there has been more interest in the protection against blunt force impacts. There exist three main threats in a military environment; motor vehicle accidents, trip and fall accidents, and the airborne environment. These problems largely exist during peacetime but still pose as potential threats. The protection against blunt force impact depends primarily on the dissipation of energy through the helmet than through the person's head. We are performing these tests to determine the best cushioning material protecting against blunt force impact. All branches of military as well as all football players will use this cushioning testing and design. This section requires us to step back and see what other possible materials and designs that can be used in order to find the best performance characteristics for the helmets. There are always ways of improving the test result, so we came up with several alternatives to our test in order to gather results so that the information we obtain may be more accurate and better serve for our final recommendation.

To help find the best solution to our problem, we will be testing six different cushioning materials and comparing their performance against each other. These six materials will include currently used padding systems as well as new or other innovative materials that may provide desired results. Current padding systems use a range of materials from expanded polystyrene (EPS), polypropylene foams, and polyurethane foams. New and innovative materials will also be taken into consideration. For example, a UK company named D3O has produced a polymer material with a dilatant (material that increases viscosity and sheer strain) that is soft and flexible during standard conditions, but locks and disperses the energy when the material is met with a high velocity impact. Any combination of materials may be tested as well to include certain properties that another may not have. The configuration or layout of the interior lining can also be changed and evaluated to make sure the seven testing locations are properly protected. The current padding systems available already have predetermined layouts that can be tested and used as a benchmark. In addition new materials used can follow current layouts but can also be configured to a new design to be tested.

Another alternative solution to our problem can be tried by testing our inserts in a live situational testing method. We would like to take five subjects and have them wear the seven types of helmets in the different testing positions. Currently we are testing our football and combat helmets on a polymer head-form that has our helmet and accelerometer attached to it. This set up will give us very accurate data for what locations of the head are receiving the most trauma yet it does not give us accurate data on how those results actually affects the user. A series of test can be done on a live subject so that we can get feedback from the test subject. This data will be very valuable to the final recommendation. When testing on a live subject we can see what positions are the most problematic to receive blunt force trauma to. Each subject would be able to fill out the feedback diagnosis form that we have made in order to monitor how each subject reacts to the test. The information we get from these test translate the numerical data we get from the accelerometer into tangible effects to the subjects head. We must use the head-form as the constant testing force that is applied to the subject while the helmet is on and strapped. The velocity of the impact will be 14.14 feet/second keeping it equal to our current testing velocity so that the process will stay consistent and our data is comparable. After the five test subjects have filled out there feedback diagnosis we will take that data and compare it with the results from the accelerometer to give the best recommendation possible based of the velocity test and the live situational test.

Statistical Testing:

For our statistical testing we will be conducting a controlled experiment.

- Hypothesis
  - Null hypothesis: "Material A" will provide the most protection and have the best properties against blunt force impact in military and athletic helmet systems.
  - Alternative hypothesis" "Material A" will not provide the most protection and have the best properties against blunt force impact in military and athletic helmet systems.
- Variables
  - Controlled variables
    - Velocity at which helmets will be dropped (14.1 ft/sec)
    - Height at which helmet will be dropped
    - Surface that helmet will be dropped on
  - Dependent Variables
    - Recorded deceleration values (G's)
    - Shock duration (time ms)
    - Material cushion curves
  - Independent Variables
    - Three different temperature conditions (14°F,70 °F,130°F)
      - The temperatures will be controlled via a conditioning chamber
    - Six different cushioning materials which will be place inside the helmet.
    - Seven different drop locations on helmets
- Data collection
  - Each of the six liner materials will be tested twice.
    - 14 impacts per liner per temperature
  - The ACH combat helmets will be reused until there is visible deformation of the helmets.
  - SaverXware collection software will capture and record data from helmet drops for analysis.

Cerebral Damage Evaluation Curve

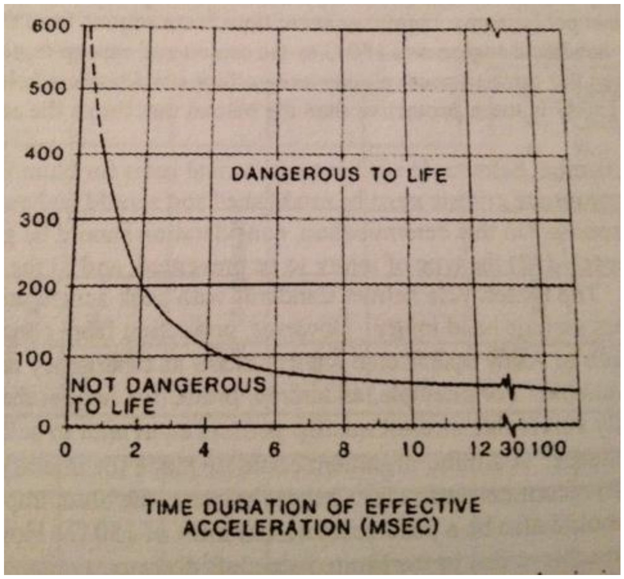

Figure 1

Layout for Graph of Helmet Locations

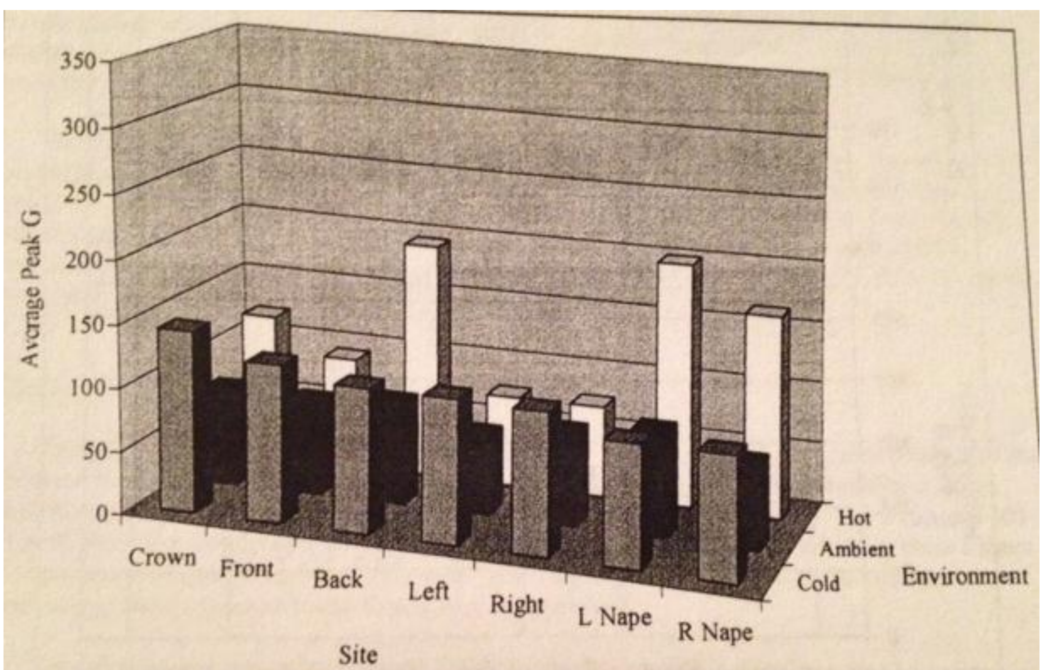

Figure 2

Testing Procedure

1. Testing equipment required
    a. 6 Advanced Combat Helmets
    b. Standard issue lining system
    c. 5 experimental liners
    d. Twin wired guide assembly
    e. Headform
    f. Tri-Axial Accelerometer
    g. Data Analyzer
    h. Misc. Tools and Equipment

2. Mechanical Setup
    a. Make sure the headform, headform adjuster, headform rotator stem, and the headform collar are securely connected.
    b. Any excessive movement or play will cause false readings of the accelerometer.

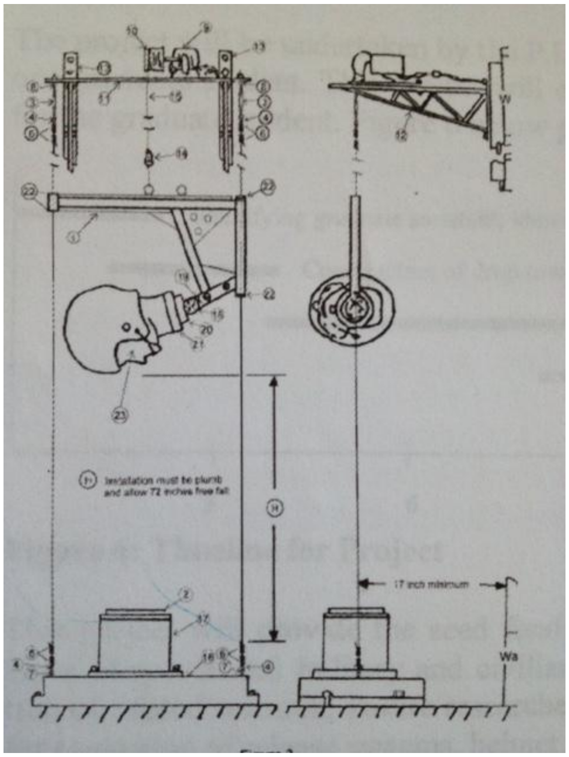

Figure 3

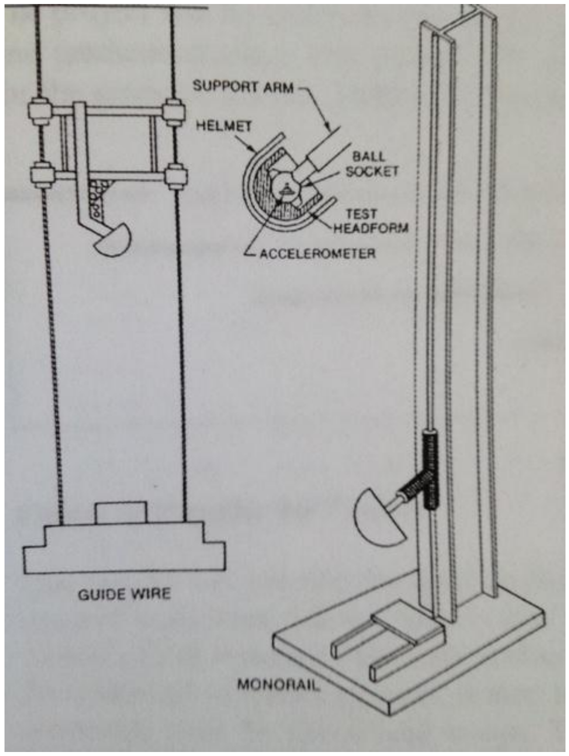

Figure 4

3. Helmet Preparation
   a. Make sure exterior and interior of the helmets are clear of any excess debris and unwanted solvents.
   b. Label the six helmets with their associated numbers and current lining material
      i. Standard Issue Liner
      ii. Experimental Liner 1
      iii. Experimental Liner 2
      iv. Experimental Liner 3
      v. Experimental Liner 4
      vi. Experimental Liner 5
   c. Each helmet will be labeled with
      i. Name of manufacturer
      ii. Test subject number
      iii. Abbreviation of liner system being used
      iv. Ex. Schutt#3Gel

d. Mark the seven impact locations on each helmet with a one inch circle and a cross. The locations will be designated and tested as followed.

   i. 1 Front
      2 Back
      3 Left Side
      4 Right Side
      5 Lower Left Nape
      6 Lower Right Nape
      7 Crown

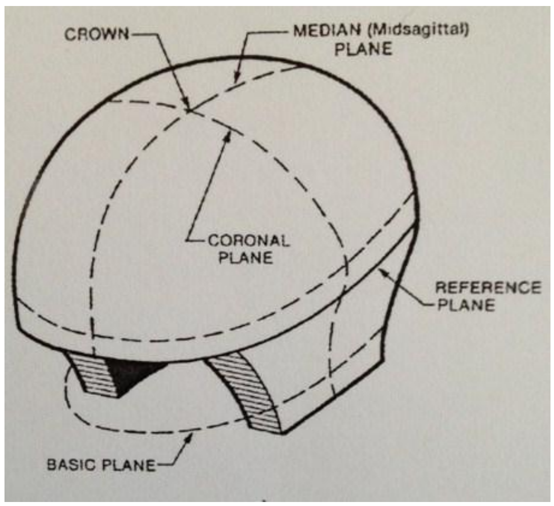

Figure 5

4. Calibration Procedures
   a. Headform Calibration
      i. Check torque of headform mounting bolt making sure it is out 180 in/lb.
   b. Attach all wires to the Tri-Axial Accelerometer making sure they are fitted securely on the headform.
   c. Tighten all bolts and check to make sure the guide wires have enough tension to drop the carriage smoothly.
   d. Drop carriage from desired height and see if alignment is correct on the drop pad.
   e. Adjust the drop height to achieve a velocity of 14.14 within 0.25 inches of the helmets contact with the impact pad.

f. Make any necessary adjustments and test again and make sure all bolts are secure.

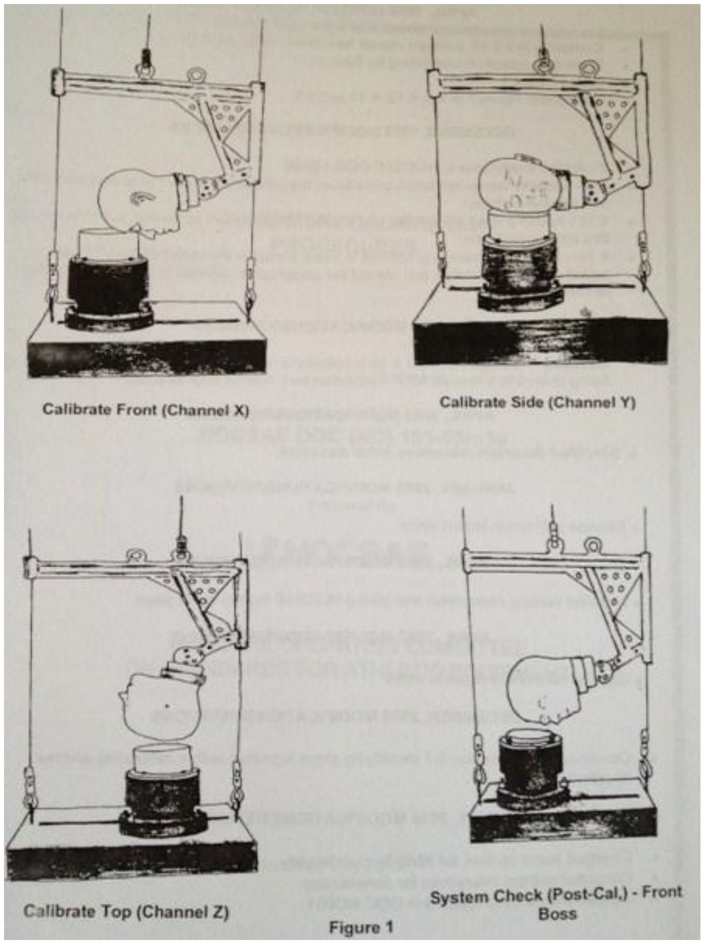

Figure 6

5. Test Method
    a. Fit helmets with corresponding padding system.
    b. Mount the helmet on the headform making sure the accelerometer is attached and plugged in.
    c. Starting with ambient temperature of 70 ± 5 ˚F

i. Take the standard issue lining as well as the five experimental linings and begin testing on the seven locations at 14.14 ft/s starting with the standard issue first as a control.
ii. Begin drop testing the seven designated locations starting with the front location.
iii. Each location will have two successive impacts. The second impact will be done between 60 and 120 seconds after the first drop.
iv. Record test data and repeat for other passing systems.

6. Helmet Conditioning
   a. Each helmet will be subject to temperature conditioning for a minimum of 12 hours before testing.
   b. The three testing temperatures will be as followed
      i. Cold 14 ± 5 ºF
      ii. Ambient 70 ± 5 ºF
      iii. Hot 130 ± 5 ºF
   c. Testing will be done within 5 minutes after being removed from the conditioning chamber.
   d. If 5 minutes pass before all drop test are completed, the helmet must be returned to the conditioning chamber for at least 15 minutes before proceeding.

7. Analyze Data and Charts
   a. Evaluate impacts
   b. Using a chart record peak G's as well as impact duration
   c. Analyze graphs

Testing Tables and Charts

Table 3

Temperature________	Helmet___	
Front	Drop 1	
	Drop 2	
Back	Drop 1	
	Drop 2	
Left Side	Drop 1	
	Drop 2	
Right Side	Drop 1	
	Drop 2	
Left Nape	Drop 1	
	Drop 2	
Right Nape	Drop 1	
	Drop 2	
Crown	Drop 1	
	Drop 2	

Table 4

Statistic		Standard Issue	Liner 1	Liner 2	Liner 3	Liner 4	Liner 5	Liner 6
Peak G	**Mean**							
	S.D.							
	Max							
Velocity (Ft/s)	**Mean**							
	S.D.							
	Max							

Table 5

Table 1 Blunt Impact Summary Statistics (14.14 Ft/s)							
	Standard Issue	Liner 1	Liner 2	Liner 3	Liner 4	Liner 5	Liner 6
Avg. Peak G Cold (14 F)							
Max Peak G Cold (14 F)							
Avg. Peak G Ambient (70 F)							
Max Peak G Ambient (70 F)							
Avg. Peak G Hot (140 F)							
Max Peak G Hot (140 F)							

Results/ Discussion

Due to the long delays in many of our required materials, our group's focus was reduced to testing various football helmets. We tested five different style of helmets manufactured by two different companies each with their own unique lining materials and layout. Our goal was to test each helmet and see which lining system performed the best at various locations on the helmet as well as the overall protection it provided at three different temperatures. After all data was collected, analysis could be started for each helmet at each temperature.

We first tested all five helmets at an ambient temperature of 70F. Looking at the graph below, we can compare the helmets and their performance to each other. At ambient temperatures, the two helmets that performed the best were helmet 3 and helmet 5. The right, left, right nape, and left nape locations provided the highest amount of protection.

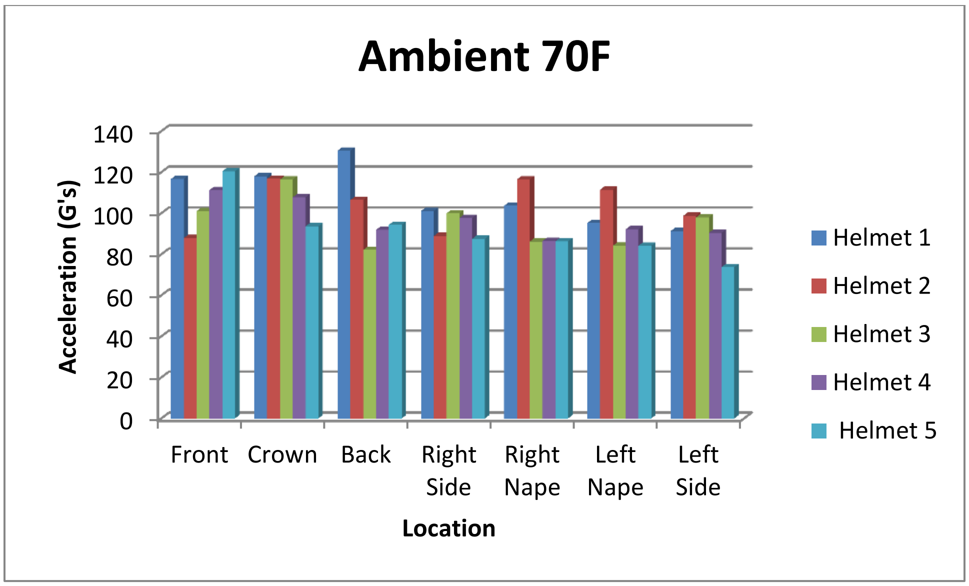

Figure 7

Table 6

Ambient	Helmet 1	Helmet 2	Helmet 3	Helmet 4	Helmet 5
Front	116.675	87.93	101.02	111.28	120.43
Crown	118	116.81	116.465	107.775	93.61
Back	130.5	106.455	82.12	91.905	94.395
Right Side	101.08	88.91	99.975	97.7	87.53
Right Nape	103.675	116.475	86.185	86.505	86.285
Left Nape	95.24	111.475	84.185	92.185	84.175
Left Side	91.255	98.76	97.9475	90.41	73.745

Next we conditioned the helmets at a temperature of 130F for 20 hours. The data collected from this temperature shows that all the values were considerably lower than those collected from ambient temperature. Besides the front impact, helmet 5 performed the best out of all the helmets. Helmet 3 performed good as well compared to the other three helmets.

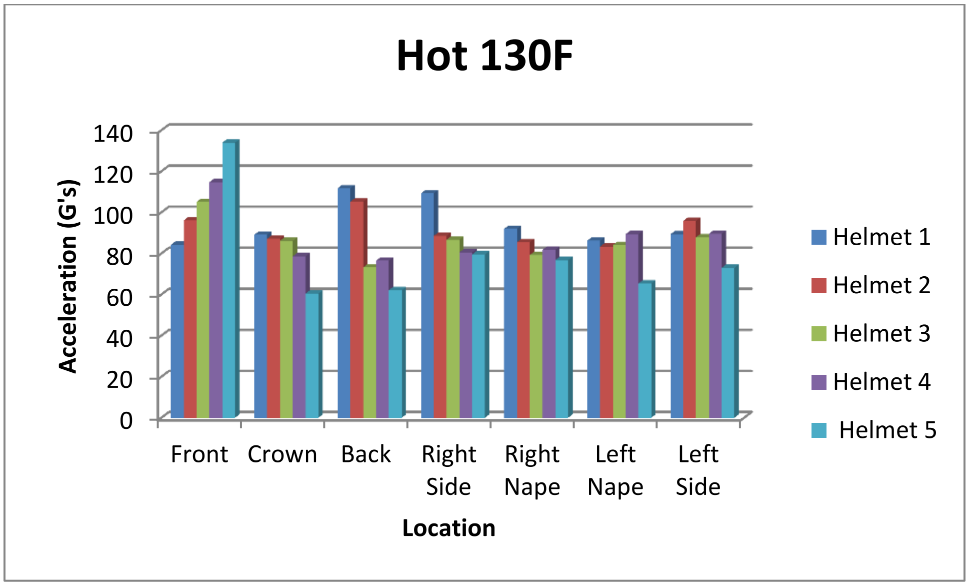

Figure 8

Table 7

Hot	Helmet 1	Helmet 2	Helmet 3	Helmet 4	Helmet 5
Front	84.225	96.13	105.13	114.735	133.95
Crown	89.13	87.165	86.145	78.64	60.435
Back	111.76	105.265	73.235	76.51	62.135
Right Side	109.265	88.575	86.675	80.56	79.55
Right Nape	92.035	85.525	79.26	81.82	76.79
Left Nape	86.27	83.365	84.14	89.425	65.42
Left Side	89.35	95.89	87.905	89.575	72.995

Finally we conditioned the helmets for 20 hours at 14F before testing. Comparing these results to the other two temperatures, the helmets did not perform as well. All acceleration values collected were considerably higher for all five helmets and provided the least amount of protection against transmitted G's. Despite the change in the temperature, helmet 5 and helmet 3 still performed better than the remainder of the helmets.

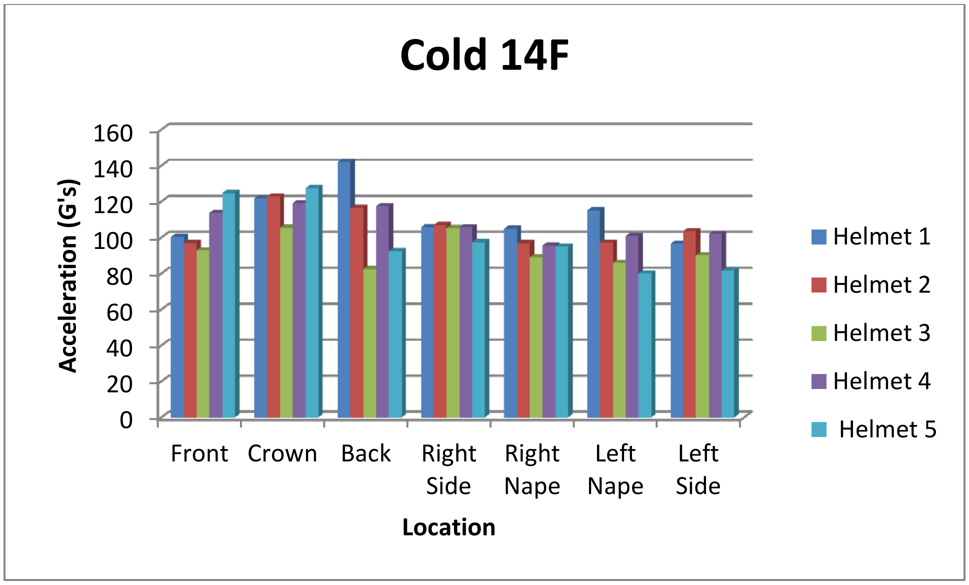

Figure 9

Table 8

Cold	Helmet 1	Helmet 2	Helmet 3	Helmet 4	Helmet 5
Front	100.405	96.94	92.84	113.715	124.715
Crown	121.71	122.76	105.405	119.12	127.46
Back	141.96	116.515	82.465	117.41	92.46
Right Side	105.755	106.94	105.3	105.64	97.425
Right Nape	104.95	96.805	88.985	95.62	95.045
Left Nape	115.13	97.16	85.91	100.88	80.01
Left Side	96.51	103.55	90.14	102	81.565

After analyzing all the helmets at each of the temperatures it is evident that helmet 5 provided the most amount of protection against blunt force impact. Helmet 3 provided the next best solution to blunt force impact. Aside from the average G's transmitted throughout the helmet locations, we also found that all helmets provided the most protection on all locations besides the front, crown, and back. Although this was discovered, it is not likely for an athlete to be hit with a large enough force at these three locations. The majority of the impacts will be seen at the right, left, right nape, and left nape locations. All impacts did not exceed the 150 G tolerance therefore providing an adequate amount of protection against cerebral damage at all of the tested locations.

Conclusion/ Observations

Initially starting the project on January 2, 2012 the plan was to test the blunt force impact performance of various helmet lining systems for military and football use. The first few weeks were devoted to building the helmet tester. The tester, guide wire free fall drop tower, was fabricated per FMVss 218 Standard. There is a very limited amount of helmet testers in the United States and Cal Poly is very privileged to have such equipment. Cal Poly graduate student Evan Cernokus was in charge of building the tester. There were many bottlenecks that arrived in the process that delayed the building of the tester. First there was trouble getting all the parts in for making the tester, then there was troubles getting the headform in and the biggest problem was getting liners in. We did not and still have not received the liners in time, so due to time constraints we were forced to only test football helmets. The liners will be available for others to perform testing on with future senior projects. Because of the time constraints and Cal Poly Football team's needs, we were only able to get five helmets testing five different liners.

While waiting for all the parts to come in and the tester to be assembled, the written part of the report took up majority of the time. There was a lot of information available on the internet for the literature reviews. Along with the literature reviews, a Gantt chart was made to map out the next twenty weeks. The Gantt chart stood as an outline for the project but was constantly being edited due to bottlenecks and project complications. The testing procedure and experimental design were created and checked off by Jay Singh and Evan Cernokus. The testing procedure was very similar to one found online. The testing procedure that was designed for combat helmets could also be used to test the football helmets.

Even though the tester was built, the liners still had not come in on time and the final deadline was getting close. While waiting for the liners to come in fixtures needed to be fabricated to hold the velocity sensor as well as the emergency shut-off switch for the tester. The machined parts took two days to make. Once the velocity height was determined, the velocity recorders were taken off the tester and wall. The height was marked on the wall with a permanent marker. All the helmets weighed the same so the height and velocity was held constant throughout testing.

On May 22, 2012 all required materials were received and testing was ready to begin. Unfortunately another problem arose with the computer system and Test Partner 3 bnot recognizing the triaxial accelerometer.   A few days later it was found that the accelerometers and were passive and required a charge from a power source in order to record data. Unfortunately the TP3 program was not able to power the accelerometer and there could not be used to collect our data. This was determined from talking with Lansmont who was the supplier of our equipment.   Almost accepting defeat the use of the TP3 program was able to be substituted with the Lansmont SaverXware. The new method for collecting our data required the use of an in-field data collecting unit (Saver 3X90) and the SaverXware program. The Saver 3X90 contained a triaxial accelerometer inside the unit itself as well as six other inputs that could allow for two other triaxial accelerometers. We used channels 4-6 since our accelerometer was located in the headform. After the initial setup details were sent to the unit, all drops and positions were recorded at a time for one helmet at one temperature. Times were also recorded for each drop in case an error occurred and needed to be deleted from the data. All helmets followed the following drop sequence: Front, crown, back, right side, lower right nape, lower left nape, left side. On Wednesday May 30th 2012 the initial testing was done. All the helmets were labeled with tape on the seven impact locations along with labeling the helmet liners one through five. The excel tables were already pre-made to ease the process of recording data. The first set of data was recorded by testing all five liners at ambient temperature. The testing room was 70 plus/minus five degrees Fahrenheit. The helmet testing was dropped at an impact velocity of 14.14 (plus/minus 3 %) feet per minute. Each of the five helmets was tested at seven different locations (front, back, left side, right side, right nape, left nape and top). Each of the seven location were tested twice to ensure accuracy of data. The times of each drop were recorded to ensure matching up of every drop. Once the data was recorded in the computer each drop could be analyzed individually and conclusions could be made from the shock graphs, recorded G's, and the recorded velocities.

All five helmets were then placed in the environmental chamber at 130 degrees Fahrenheit overnight. The following evening they were tested. Velocity was held constant at 14.14 (plus/minus 3 %) feet per minute. The helmets were tested just like they were at ambient, with the only variation being the temperature. Unfortunately there was a setback with the wires. The wires being sensitive caused many problems throughout the testing. The wires had to be re-soldered a few times but the results were inaccurate. The wires from the old tester were switched and used to record the data onto the savor.

All five helmets were placed in the environmental chamber again at 14 degrees Fahrenheit. They were held in the chamber overnight and tested the following day. The testing on the third day went a lot smoother and there weren't any complications. Coming up with a lean process for testing by the third day enabled us to ensure the best results and at a much faster pace.

Once all the testing was done it was time to analyze and come to a conclusion. Below is a breakdown of each of the five helmets. Overall the point of the project was to figure out which liner provided the best protection by having the lowest number of G's, and which location on the helmet provided the most protection. Football helmet manufacturers take into account where most football players would be hit and account for that in manufacturing.

Results for Helmet #1:

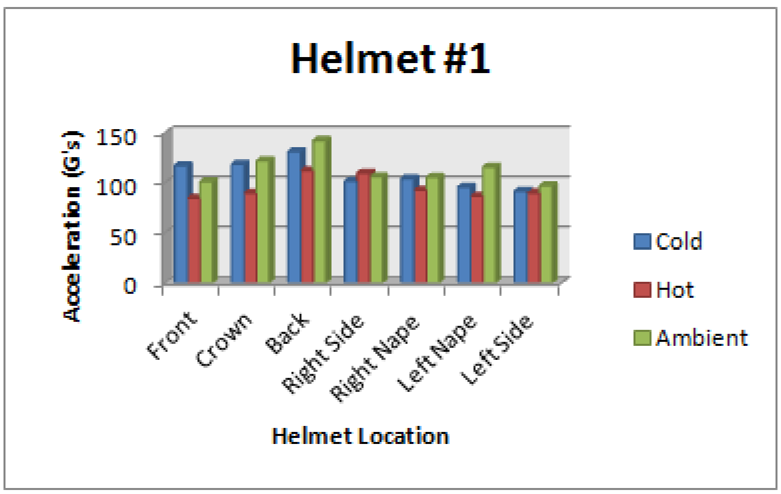

Figure 10

As you can see from the **Figure 10** it is evident that the greatest protection at any overall temperature is the left and right side of the helmet. The worst protection is the back which is the least impacted spot for football players. Since most players are hit from the front and sides, the protection is highly valued at those locations. Most football players have a raised body temperature while they are playing, so it is good that the most protection observed was under hot conditions. Cold conditions are shown to be the worst for this helmet but ambient conditions were very close.

Results for Helmet #2:

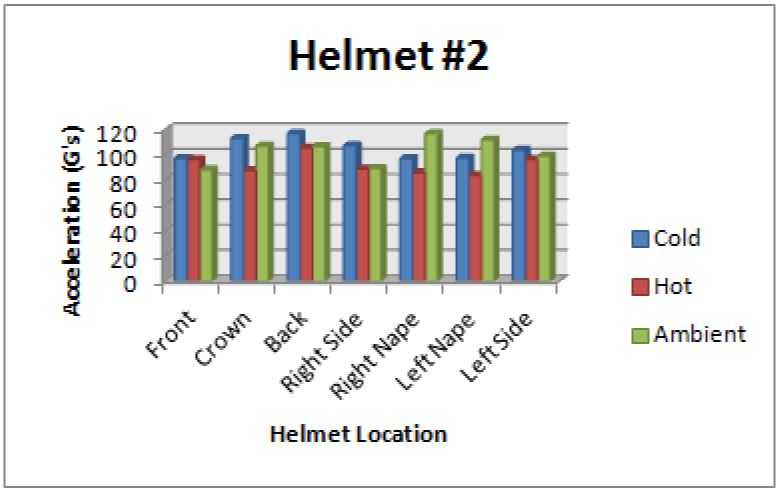

Figure 11

As you can see from **Figure 11** the sides provided consistent protection at the variety of conditions, however overall the front provided the best protection. The sides provided great protection under cold and hot conditions but not in ambient conditions. The temperature of an athlete's head will be between ambient and hot, therefore ambient temperature performance should be increased to provide maximum protection. Hot provided the best protection at the seven varying impact points and cold provided the worst protection.

Results for Helmet #3:

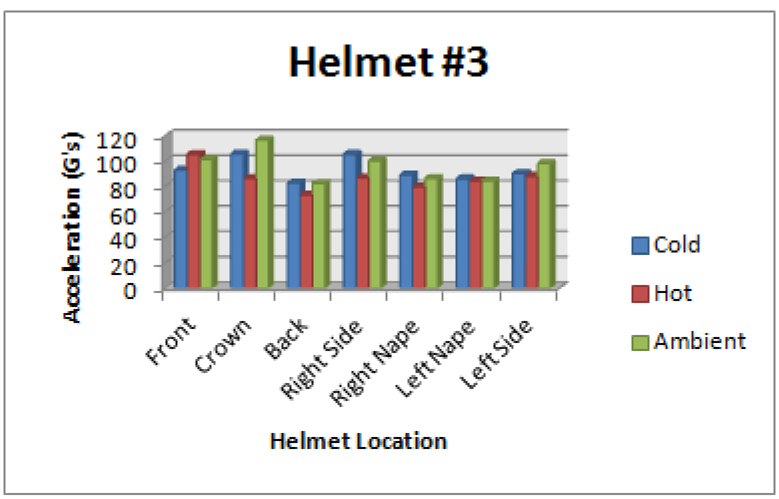

Figure 12

As you can see in **Figure 12** the hot conditions provided the best protection overall at all seven impact points. The right and left nape provided good consistent protection at all three temperatures. Unlike helmet one and helmet two, the back provided the greatest protection at all three temperatures. The worst was the crown which does not typically get punctured in football. Overall Helmet three provided the best protection at all temperatures and at all seven impact spots. Helmet three was the newest of the Schutt helmets and it would be recommended that Cal Poly invested in more helmets much like number three. Number three was a gel padding that was able to absorb shock very well.

Results for Helmet #4:

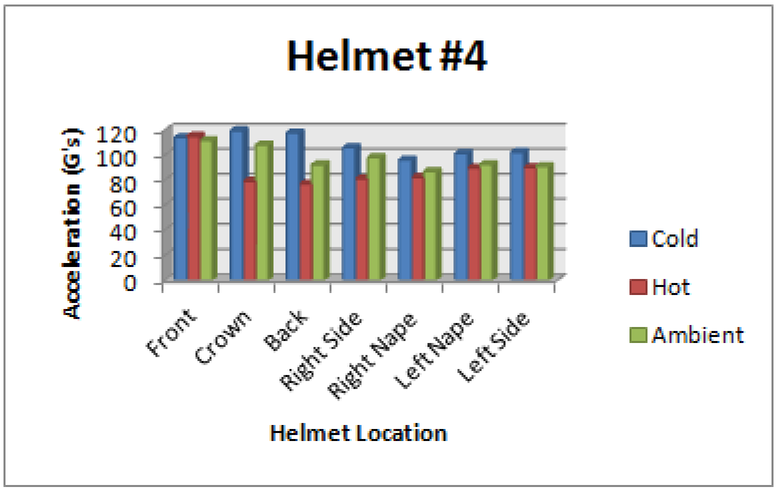

Figure 13

As you can see in **Figure 13**, much like the previous three helmets, hot temperature provided for the greatest results. The right side, right nape, left side, and left nape were the most consistent under the three temperature conditions. Helmet four did best under hot and ambient conditions which are the ultimate goal of football helmets. The head being one of the hottest parts of the body should never reach cold temperatures. Helmet four should not be used in places that reach cold temperatures or snow.

Results for Helmet #5:

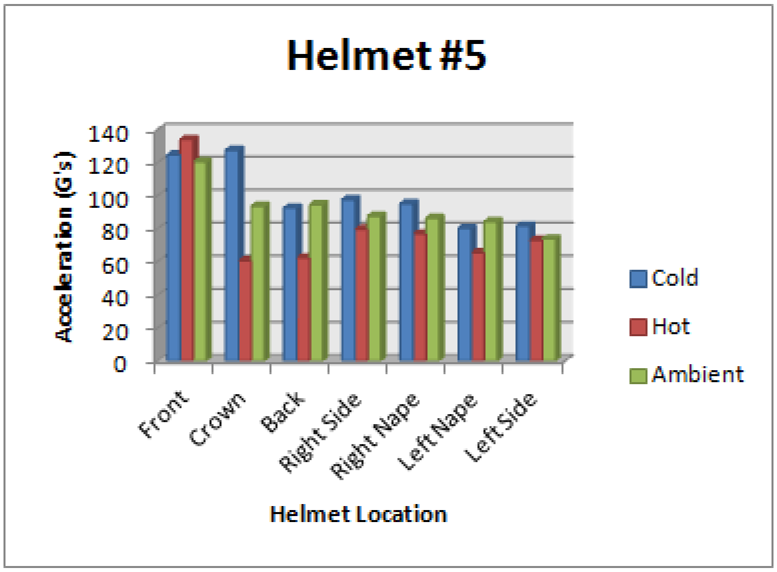

Figure 14

As you can see from **Figure 14**, helmet five data was slightly different than the previous helmets. At hot temperature the crown and back provided the best protection. The sides were still consistently protective at all three temperatures however the crown had the lowest number of G's absorbed at hot temperature. The front of the helmet provided the worst protection overall across all three temperatures.

Overall Blunt Impact Summary:

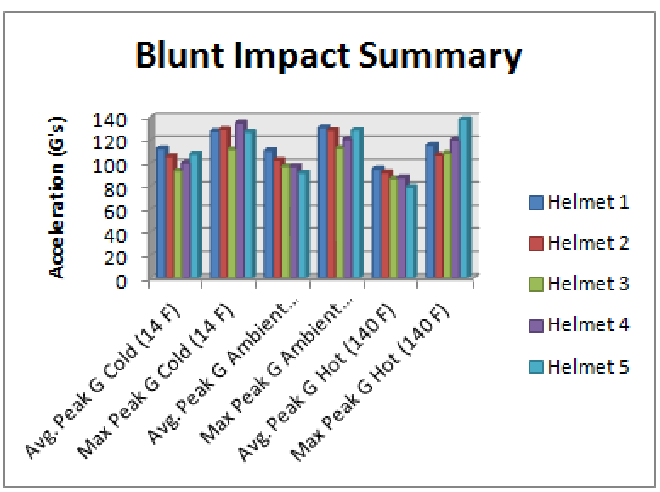

Figure 15

Above is the overall summary of all the helmets (**Figure 15**) at the three temperatures with all seven impact points combined. The helmet that would be recommended for athletes playing in cold temperatures would be helmet three. The helmet that would be recommended for athletes playing in ambient weather conditions would be helmet five. The helmet that would be recommended for athletes playing in hot condition would be helmet number five. When looking at the results as a whole and throwing out the outliers it was concluded that helmet three provides for the greatest protection for all three temperatures and the seven different impact points. Based on these findings Cal Poly should invest in helmet number three for its athletes. Different football positions are impacted in different locations of the helmet therefore, Cal Poly should use the data found to find the perfect helmet for every position.

One of the biggest things learned from this project was how to handle all the real world problems that occurred. Every problem that occurred was a life learning lesson that will be taken with us out in the real world. All the shipping delays provided us with a learning experience about lead times and how they may not always turn out the way it was initially scheduled. Another great learning experience was that the more you rely on others help to get things accomplished the harder it becomes. We relied heavily on the US Navy to ship us liners, which did not work out the way we had planned. We also learned that everything won't necessarily go as planned and you have to expect various delays and setbacks. For example when making a Gantt chart it is important to take into account time for things that could go wrong. Planning and preparation is used to try and avoid any problems that could arise. Planning is a very important key step to success and necessary for projects such as this.

There were some factors of our data that we could not pin point in our analysis. The acceleration that was recorded for each helmet was not consistent throughout our entire test. For instance while testing helmet 2 on the front section, the acceleration measured for the two drops were 62.48 G's and 113.38 G's. The difference between these two drops in the same spot is 50.9 G's, which is almost 1/3 less than its previous drop. This error can be due to many factors ranging from the accelerometer to how much tension was in the lead wires when the helmet was released. The problem stemmed from the fact that we had to complete one full series of test before we could download the data to the computer and read the results. It would have been beneficial to have the reading of the drops real time so that we could re-test if necessary. This instance only happened on a few occasions so this problem did not skew our data very much.

Another aspect of our process that was not as sound as we hoped was the testing temperature. To control the temperature of our project we conditioned the helmets to two different temperatures, 14 and 130 degrees Fahrenheit. The problem we found was that each one of our helmet test took between 15 and 18 minutes, so by the end of our test the helmets were not at the same temperature they were at when the testing started. We did realize that this occurrence would happen for all the helmets that we tested so that the data will at least be comparable between each helmet. The only way we could have avoided this problem would be to conduct the test in an environmental chamber big enough to house the testing equipment as well as the test operators. Another solution to that problem would be to place the helmet back into the environmental chamber for at least 12 hours after every 2 drops on the helmet. In the cold situational testing, the acceleration of the test would actually be higher than the data we collected for the helmets. This is due to the fact that as the helmet gets warmer back towards the ambient temperature, there is a better impact resistance. This is the exact opposite for the helmets condition to the 130 degree temperature. As the helmets cool down the stiffness of the padding increases which causes the acceleration to be higher than what the data should be. With these two issues we still conducted the test as accurately and evenly distributed as possible.

This project has many different avenues you can take to conduct other test. A test we thought about doing is to see how much affect the amount of air in the liners has to do with cushioning and concussion prevention. In our test we took all the air out the helmets so that all the helmets were the same. This test is applicable because players have two choices when picking a helmet to use. They can either pick a helmet that is the right size and put no air in it, or you can get a bigger helmet and fill it up with the desired amount of air. It would be interesting to see the results that would come from this test. It would be beneficial to know what amount of psi is best suitable to cause the least amount of G's in testing and prevent concussion. This test can easily be regulated by pumping the helmet liners with air then measuring the psi in the liner before each test to make sure it stays consistent. This knowledge would be helpful as well for teams that travel long distances in football such as collegiate and professional due to the fact that elevation changes can cause the air in the liners to expand or contract.

The information we gained from this project can be easily analyzed and incorporated into the decisions made when purchasing football helmets. If a team tends to play in warm weather cities or states then they should purchase a majority of helmet 5's. If you happen to be playing a lot of teams in cold/sub-zero places then you should purchase helmet 3's. From this data we also spark the interest in the redesign of some of the padding in certain areas of the helmets. In the NFL a majority of the concussions happen when players get whiplash and the back of their helmet hits the ground. In our test we can see that the highest acceleration reading were from the front and back of the helmet. This is an obvious place were the padding system should be refined. This project has a lot of opportunity to be relevant in today's football society due to the fact of the raging concussion problems. With this data along with some future test that we have conducted we feel that we can get accurate data on the safety of our helmets as well as how to properly inflate them so it protects you as much as possible.

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Appendix

Gantt:

Updated Schedule:

Task 1: Set requirements for testing and establish project timeline

- Define the scope of the project. Completion Date: 1/25/12
    - Jaclyn, Ryan, Darren
- Develop a Gantt/Task chart and team scheduling. Completion Date: 1/31/12
    - Jaclyn, Ryan, Darren
- Conduct preliminary research on materials used. (on-going)
    - Jaclyn, Ryan, Darren
- Set up testing equipment and calibration. Completion Date: 2/8/12
    - Evan Cernokus
- Collect Combat and Football helmets for testing. (on- going)
    - Jaclyn, Ryan, Darren
- Contact Jay for donation email Completion Date: 2/1/12
    - Jaclyn
- Contact Cal Poly Head Coach for Helmets Completion Date:2/1/12
    - Ryan
- Contact 1LT Brian Calcagno for helmet donations Completion Date:2/1/12
    - Ryan

Task 2: Create a testing procedure

- Research different testing procedures for the Blunt Impact Testing Completion Date: 2/20/12
    - Jaclyn, Darren, Ryan
- Draft up our testing procedure Completion Date 2/22/12
    - Darren, Jaclyn, Ryan
- Contact Camp Roberts CIF Completion Date 2/28/12
    - Darren

- Contact Vandenberg Air Force Base in Lompoc at the Defense Reutilization and Marketing Organization Completion Date: 2/28/12
    - Jaclyn

Task 3: Do initial testing of current helmets used

- Finalize testing procedures 4/24/12
    - Darren, Jaclyn, Ryan, Evan
- Become familiar with the drop test procedure and the program being used
    - Evan, David, Jaclyn, Ryan, Darren
- Develop Excel Spreadsheets
    - Pre-Develop excel spreadsheets to hold the data recorded 4/24/12
    - Darren, Jaclyn, Ryan
- Complete the experimental design 4/24/12
    - Darren, Jaclyn, Ryan, Jay
- Run all test procedures on current helmets and set as control Completion Date: 4/30/12
    - Jaclyn, Ryan, Darren

Task 4: Run testing on different cushioning at different angles

- Test helmet under three different environmental conditions Completion Date: 6/1/12
    - Jaclyn, Ryan, Darren
- Perform drop test on seven different helmet locations Completion Date: 6/1/12
    - Jaclyn, Ryan, Darren

Task 5: Analyze data and evaluate

- Perform different testing scenarios and analyze cushion curve from the different performance testing. Completion Date: 6/1/12
    - Jaclyn, Ryan, Darren

Task 6: Correlate the data with the adverse effects on cerebral damage

- Evaluate effectiveness of various cushioning Completion Date: 6/7/12
    - Jaclyn, Ryan, Darren

- Determine level of damage prevention Completion Date: 6/7/12
    - Jaclyn, Ryan, Darren

Task 7: Presentaions 6/5/12

- Construct a poster board
- Present in the Dynamics lab
    - Jaclyn, Ryan, Darren

Task 8: Write final recommendation

- According to gathered data, recommend the best material for blunt impact cushioning Completion Date: 6/7/12
    - Jaclyn, Ryan, Darren
- Include all helmet test data Completion Date: 6/8/12
    - Jaclyn, Ryan, Darren

Task 9: Submit final project and present to advisors Completion Date: 6/8/12

- Jaclyn, Ryan, Darren

Average of Helmet #1

	Cold	Hot	Ambient
Front	100.405	84.225	116.675
Crown	121.71	89.13	118
Back	141.96	111.76	130.5
Right Side	105.755	109.265	101.08
Right Nape	104.94	92.035	103.675
Left Nape	115.13	86.27	95.24
Left Side	96.51	89.35	91.255

Average of Helmet #2

	Cold	Hot	Ambient
Front	96.94	96.13	87.93
Crown	112.76	87.165	106.81
Back	116.515	105.265	106.455
Right Side	106.94	88.575	88.91
Right Nape	96.805	85.525	116.475
Left Nape	97.16	83.365	111.445
Left Side	103.55	95.89	98.76

Average of Helmet #3

	Cold	Hot	Ambient
Front	92.84	105.13	101.02
Crown	105.405	86.145	116.465
Back	82.465	73.235	82.12
Right Side	105.3	86.675	99.975
Right Nape	88.985	79.26	86.185
Left Nape	85.91	84.14	84.185
Left Side	90.14	87.905	97.9475

Averages of Helmet #4

	Cold	Hot	Ambient
Front	113.715	114.735	111.28
Crown	119.12	78.64	107.775
Back	117.41	76.51	91.905
Right Side	105.64	80.56	97.7
Right Nape	95.62	81.82	86.505
Left Nape	100.88	89.425	92.185
Left Side	101.895	89.575	90.41

Averages of Helmet #5

	Cold	Hot	Ambient
Front	124.715	133.95	120.43
Crown	127.46	60.435	93.61
Back	92.46	62.135	94.395
Right Side	97.425	79.55	87.53
Right Nape	95.045	76.79	86.285
Left Nape	80.01	65.42	84.175
Left Side	81.565	72.995	73.745

Image 1

Image 2

Image 3

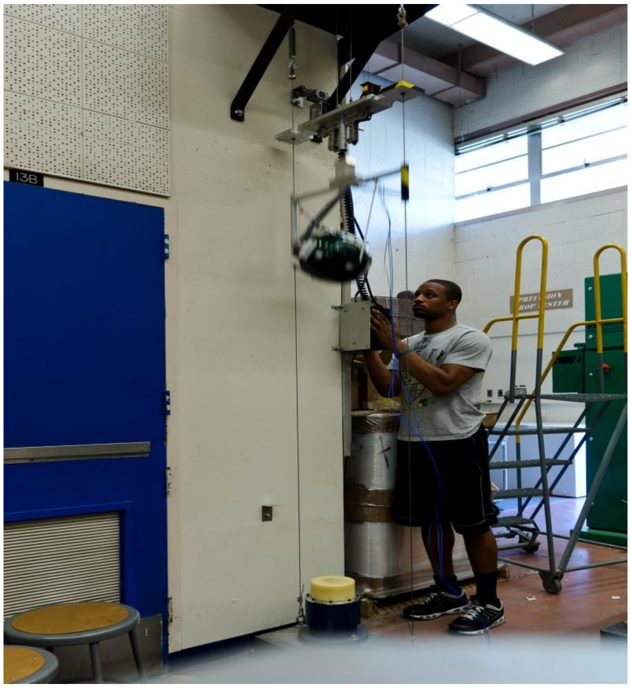

Image 4

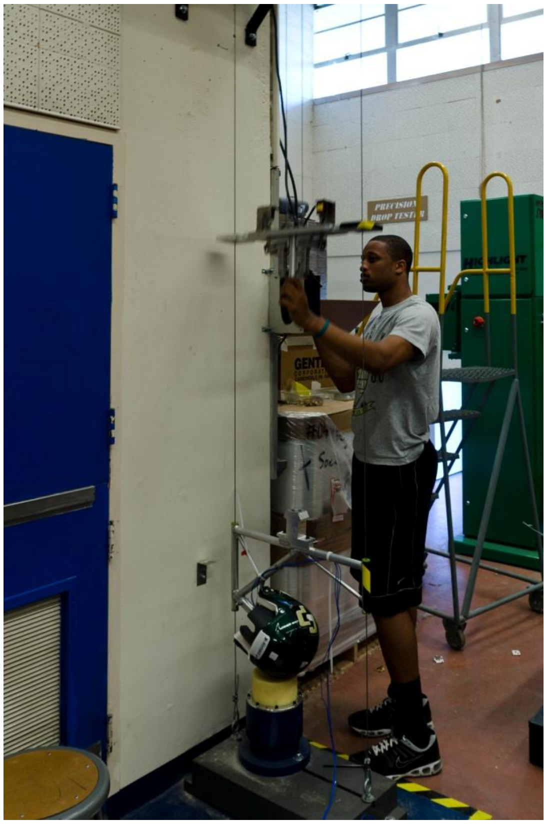

Image 5: Example of the Shock Chart

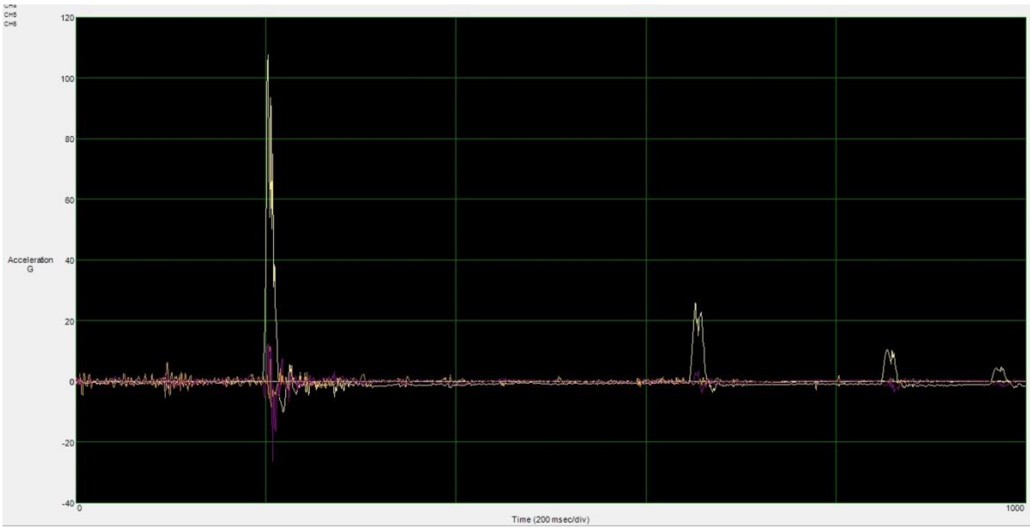

Table 9:

Table 1 Blunt Impact Summary Statistics (14.14 Ft/s)					
	Helmet 1	Helmet 2	Helmet 3	Helmet 4	Helmet 5
Avg. Peak G Cold (14 F)	112.34	105.81	93.01	99.81	107.75
Max Peak G Cold (14 F)	127.61	129.03	111.49	134.86	126.86
Avg. Peak G Ambient (70 F)	110.70	102.40	96.73	96.82	91.45
Max Peak G Ambient (70 F)	130.87	128.38	112.83	120.58	128.52
Avg. Peak G Hot (140 F)	94.58	91.70	86.07	87.32	78.75
Max Peak G Hot (140 F)	115.29	106.93	108.47	120.1	137.75

Table 10:

Temperature Ambient 70F		**Helmet** #1	Time
Front	Drop 1	111.38	6:07:00
	Drop 2	121.97	6:08:00
	Average	116.675	
Crown	Drop 1	106.51	6:14:00
	Drop 2	129.49	6:15:00
	Average	118	
Back	Drop 1	130.13	6:18:00
	Drop 2	130.87	6:19:00
	Average	130.5	
Right Side	Drop 1	94.4	6:22:00
	Drop 2	107.76	6:23:00
	Average	101.08	
Right Nape	Drop 1	101.21	6:25:00
	Drop 2	106.14	6:26:00
	Average	103.675	
Left Nape	Drop 1	94.14	6:28:00
	Drop 2	96.34	6:29:00
	Average	95.24	
Left Side	Drop 1	85.16	6:33:00
	Drop 2	97.35	6:34:00
	Average	91.255	

Table 11:

Temperature Ambient 70F **Helmet** #2			Time
Front	Drop 1	62.48	6:50:00
	Drop 2	113.38	6:51:00
	Average	87.93	
Crown	Drop 1	107.81	6:53:00
	Drop 2	105.81	6:54:00
	Average	106.81	
Back	Drop 1	108.56	6:55:00
	Drop 2	104.35	6:56:00
	Average	106.455	
Right Side	Drop 1	83.87	6:58:00
	Drop 2	93.95	7:01:00
	Average	88.91	
Right Nape	Drop 1	113.03	7:03:00
	Drop 2	119.92	7:04:00
	Average	116.475	
Left Nape	Drop 1	128.38	7:06:00
	Drop 2	94.51	7:07:00
	Average	111.445	
Left Side	Drop 1	91.02	7:09:00
	Drop 2	106.5	7:10:00
	Average	98.76	

Table 12:

Temperature Ambient 70F **Helmet** #3			Time
Front	Drop 1	103.14	7:18:00
	Drop 2	98.9	7:19:00
	Average	101.02	
Crown	Drop 1	120.1	7:21:00
	Drop 2	112.83	7:22:00
	Average	116.465	
Back	Drop 1	90.5	7:23:00
	Drop 2	73.74	7:24:00
	Average	82.12	
Right Side	Drop 1	101.72	7:25:00
	Drop 2	98.23	7:26:00
	Average	99.975	
Right Nape	Drop 1	84.36	7:27:00
	Drop 2	88.01	7:28:00
	Average	86.185	
Left Nape	Drop 1	76.72	7:30:00
	Drop 2	91.65	7:31:00
	Average	84.185	
Left Side	Drop 1	111.71	7:32:00
	Drop 2	102.62	7:33:00
	Average	97.9475	

Table 13:

Temperature Ambient 70F **Helmet** #4			Time
Front	Drop 1	120.58	7:43:00
	Drop 2	101.98	7:44:00
	Average	111.28	
Crown	Drop 1	114.67	7:46:00
	Drop 2	100.88	7:48:00
	Average	107.775	
Back	Drop 1	91.66	7:49:00
	Drop 2	92.15	7:50:00
	Average	91.905	
Right Side	Drop 1	105.19	7:52:00
	Drop 2	90.21	7:53:00
	Average	97.7	
Right Nape	Drop 1	82.78	7:54:00
	Drop 2	90.23	7:55:00
	Average	86.505	
Left Nape	Drop 1	97.57	7:57:00
	Drop 2	86.8	7:58:00
	Average	92.185	
Left Side	Drop 1	89.97	7:59:00
	Drop 2	90.85	8:00:00
	Average	90.41	

Table 14:

Temperature Ambient 70F **Helmet** #5			Time
Front	Drop 1	112.34	8:15:00
	Drop 2	128.52	8:16:00
	Average	120.43	
Crown	Drop 1	112.17	8:17:00
	Drop 2	75.05	8:18:00
	Average	93.61	
Back	Drop 1	99.22	8:19:00
	Drop 2	89.57	8:20:00
	Average	94.395	
Right Side	Drop 1	89.53	8:22:00
	Drop 2	85.53	8:23:00
	Average	87.53	
Right Nape	Drop 1	87.83	8:25:00
	Drop 2	84.74	8:26:00
	Average	86.285	
Left Nape	Drop 1	91.65	8:27:00
	Drop 2	76.7	8:28:00
	Average	84.175	
Left Side	Drop 1	68.96	8:29:00
	Drop 2	78.53	8:30:00
	Average	73.745	

Table 15:

Temperature Hot 130F **Helmet** #1			Time
Front	Drop 1	81.74	7:48:00
	Drop 2	86.71	7:49:00
	Average	84.225	
Crown	Drop 1	86.98	7:51:00
	Drop 2	91.28	7:53:00
	Average	89.13	
Back	Drop 1	108.23	7:55:00
	Drop 2	115.29	7:56:00
	Average	111.76	
Right Side	Drop 1	104.75	7:57:00
	Drop 2	113.78	7:58:00
	Average	109.265	
Right Nape	Drop 1	97.2	7:59:00
	Drop 2	86.87	8:00:00
	Average	92.035	
Left Nape	Drop 1	86.71	8:01:00
	Drop 2	85.83	8:02:00
	Average	86.27	
Left Side	Drop 1	86.27	8:03:00
	Drop 2	92.43	8:04:00
	Average	89.35	

Table 16:

Temperature Hot 130F **Helmet** #2			Time
Front	Drop 1	86.5	8:14:00
	Drop 2	105.76	8:15:00
	Average	96.13	
Crown	Drop 1	88.62	8:16:00
	Drop 2	85.71	8:17:00
	Average	87.165	
Back	Drop 1	103.6	8:18:00
	Drop 2	106.93	8:19:00
	Average	105.265	
Right Side	Drop 1	95.44	8:20:00
	Drop 2	81.71	8:22:00
	Average	88.575	
Right Nape	Drop 1	88.58	8:23:00
	Drop 2	82.47	8:24:00
	Average	85.525	
Left Nape	Drop 1	80.5	8:25:00
	Drop 2	86.23	8:26:00
	Average	83.365	
Left Side	Drop 1	94.61	8:28:00
	Drop 2	97.17	8:29:00
	Average	95.89	

Table 17:

Temperature Hot 130F **Helmet** #3			Time
Front	Drop 1	108.47	9:53:00
	Drop 2	101.79	9:54:00
	Average	105.13	
Crown	Drop 1	84.09	9:56:00
	Drop 2	88.2	9:57:00
	Average	86.145	
Back	Drop 1	72.45	9:58:00
	Drop 2	74.02	9:59:00
	Average	73.235	
Right Side	Drop 1	87.07	10:01:00
	Drop 2	86.28	10:02:00
	Average	86.675	
Right Nape	Drop 1	84.14	10:03:00
	Drop 2	74.38	10:07:00
	Average	79.26	
Left Nape	Drop 1	84.69	10:04:00
	Drop 2	83.59	10:05:00
	Average	84.14	
Left Side	Drop 1	87.59	10:08:00
	Drop 2	88.22	10:10:00
	Average	87.905	

Table 18:

Temperature Hot 130F **Helmet** #4			Time
Front	Drop 1	120.1	9:12:00
	Drop 2	109.37	9:13:00
	Average	114.735	
Crown	Drop 1	80.47	9:14:00
	Drop 2	76.81	9:15:00
	Average	78.64	
Back	Drop 1	67.68	9:16:00
	Drop 2	85.34	9:17:00
	Average	76.51	
Right Side	Drop 1	71.53	9:18:00
	Drop 2	89.59	9:19:00
	Average	80.56	
Right Nape	Drop 1	79.7	9:21:00
	Drop 2	83.94	9:22:00
	Average	81.82	
Left Nape	Drop 1	82.71	9:23:00
	Drop 2	96.14	9:24:00
	Average	89.425	
Left Side	Drop 1	87.9	9:26:00
	Drop 2	91.25	9:27:00
	Average	89.575	

Table 19:

Temperature Hot 130F **Helmet** #5			Time
Front	Drop 1	137.75	9:31:00
	Drop 2	130.15	9:32:00
	Average	133.95	
Crown	Drop 1	59.41	9:34:00
	Drop 2	61.46	9:35:00
	Average	60.435	
Back	Drop 1	63.96	9:37:00
	Drop 2	60.31	9:38:00
	Average	62.135	
Right Side	Drop 1	74.43	9:40:00
	Drop 2	84.67	9:41:00
	Average	79.55	
Right Nape	Drop 1	81.86	9:42:00
	Drop 2	71.72	9:43:00
	Average	76.79	
Left Nape	Drop 1	63.26	9:46:00
	Drop 2	67.58	9:47:00
	Average	65.42	
Left Side	Drop 1	79.94	9:49:00
	Drop 2	66.05	9:50:00
	Average	72.995	

Table 20:

Temperature Cold 14F **Helmet** #1			Time
Front	Drop 1	90.87	3:08:00
	Drop 2	109.94	3:09:00
	Average	100.405	
Crown	Drop 1	127.61	3:10:00
	Drop 2	115.81	3:11:00
	Average	121.71	
Back	Drop 1	142.91	3:12:00
	Drop 2	141.01	3:13:00
	Average	141.96	
Right Side	Drop 1	102.92	3:14:00
	Drop 2	108.59	3:15:00
	Average	105.755	
Right Nape	Drop 1	104.18	3:16:00
	Drop 2	105.7	3:17:00
	Average	104.94	
Left Nape	Drop 1	115.1	3:18:00
	Drop 2	115.16	3:19:00
	Average	115.13	
Left Side	Drop 1	102.11	3:23:00
	Drop 2	90.91	3:24:00
	Average	96.51	

Table 21:

Temperature Cold 14F **Helmet** #2			Time
Front	Drop 1	102.86	3:27:00
	Drop 2	91.02	3:28:00
	Average	96.94	
Crown	Drop 1	129.03	3:29:00
	Drop 2	116.49	3:30:00
	Average	122.76	
Back	Drop 1	118.19	3:32:00
	Drop 2	114.84	3:33:00
	Average	116.515	
Right Side	Drop 1	104.14	3:34:00
	Drop 2	109.74	3:35:00
	Average	106.94	
Right Nape	Drop 1	94.93	3:36:00
	Drop 2	98.68	3:37:00
	Average	96.805	
Left Nape	Drop 1	96.6	3:38:00
	Drop 2	97.72	3:38:00
	Average	97.16	
Left Side	Drop 1	100.15	3:39:00
	Drop 2	106.95	3:40:00
	Average	103.55	

Table 22:

Temperature Cold 14F **Helmet** #3			Time
Front	Drop 1	99.79	3:43:00
	Drop 2	85.89	3:44:00
	Average	92.84	
Crown	Drop 1	111.44	3:46:00
	Drop 2	99.37	3:47:00
	Average	105.405	
Back	Drop 1	71.86	3:49:00
	Drop 2	93.07	3:49:00
	Average	82.465	
Right Side	Drop 1	99.11	3:51:00
	Drop 2	111.49	3:52:00
	Average	105.3	
Right Nape	Drop 1	81.02	3:53:00
	Drop 2	96.95	3:54:00
	Average	88.985	
Left Nape	Drop 1	70.5	3:55:00
	Drop 2	101.32	3:56:00
	Average	85.91	
Left Side	Drop 1	89.52	3:58:00
	Drop 2	90.76	3:59:00
	Average	90.14	

Table 23:

Temperature Cold 14F **Helmet** #4			Time
Front	Drop 1	126.84	4:05:00
	Drop 2	100.59	4:06:00
	Average	113.715	
Crown	Drop 1	111.38	4:07:00
	Drop 2	126.86	4:08:00
	Average	119.12	
Back	Average	117.94	4:10:00
	Drop 2	116.88	4:12:00
	Average	117.41	
Right Side	Drop 1	110.25	4:13:00
	Drop 2	101.03	4:14:00
	Average	105.64	
Right Nape	Drop 1	99.18	4:15:00
	Drop 2	92.06	4:16:00
	Average	95.62	
Left Nape	Drop 1	98.16	4:17:00
	Drop 2	103.6	4:18:00
	Average	100.88	
Left Side	Drop 1	112.19	4:19:00
	Drop 2	91.6	4:20:00
	Average	101.895	

Table 24:

Temperature Cold 14F **Helmet** #5			Time
Front	Drop 1	134.86	4:22:00
	Drop 2	114.57	4:23:00
	Average	124.715	
Crown	Drop 1	132.84	4:24:00
	Drop 2	122.08	4:25:00
	Average	127.46	
Back	Drop 1	92.04	4:26:00
	Drop 2	92.88	4:27:00
	Average	92.46	
Right Side	Drop 1	104.13	4:28:00
	Drop 2	90.72	4:29:00
	Average	97.425	
Right Nape	Drop 1	96.29	4:30:00
	Drop 2	93.8	4:31:00
	Average	95.045	
Left Nape	Drop 1	81.71	4:33:00
	Drop 2	78.31	4:33:00
	Average	80.01	
Left Side	Drop 1	80.21	4:35:00
	Drop 2	82.92	4:37:00
	Average	81.565	