6-2013

History of Concussion Research in American Football

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By

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Submitted in partial fulfillment

of the requirements for

Honors in the Department of Bioengineering

Union College

June, 2013

Introduction

Concussions have been the topic of discussion in the news and media in recent years for their profound impact on today's sport industry. Athletes have become bigger, faster, and stronger then in the past, increasing the chance of injury. This can been seen in all sports. Contact sports specifically have seen a rise in mild traumatic brain injuries (MTBIs) over the years. Extensive research has been done to determine the causes of concussion, the short and long term effects of brain injury, and better ways to reduce the risk in sports. Concussion research in athletics has mainly focused on American football. The nature of the sport causes an increased occurrence of concussion then other sports. In the NFL, between 2000 and 2004, concussions were the fifth most commonly occurring injury.[14] Even with the research performed, concussion rates are still increasing, showing the need for more research.[2]

In years past, head injuries were usually shrugged off and players were allowed to return to their sports when the immediate symptoms of headaches and dizziness were reduced. Research has now shown that these head impacts may have both short-term and long-term effects and people have begun to take them more seriously. Parents today are reluctant to allow their children to take part in sports such as football, choosing to place them in non-contact sports in order to remove them from the risk of head injuries. Some former professional football players, who grew up playing and making a living from the game, have said they will not let their children play. They are not willing to subject their kids to the short and long-term effects that multiple concussions will undoubtedly have playing the game.

Concussions and head injuries will always be a part of the game of football. Nothing will change the nature of the game. That being said, the only thing that can be done is reducing the chance of injury. The focus of current research is to better understand source of concussion, and to find ways to make the game safer. Rule changes, strict officiating, and punishment, such as suspension and fines in the NFL, have occurred in recent years to try and make the game safer from an administrative standpoint. On the field, improvements in helmet design hope to reduce concussion at the point of impact.

Defining a Concussion

Concussions are a particularly difficult injury to deal with merely because there are so many different definitions of the word. WebMD defines a concussion as a common but not severe traumatic brain injury caused by a sudden bump to the head[3]. Others have defined it as "clinical syndrome characterized by immediate and transient post traumatic impairment of neural function."[11] When impacted, the brain moves around inside the skull, causing bruising, damage of nerves and damage blood vessels[3]. It's hard to definitively say what is and what isn't a concussion because the results from the impact can vary. Some believe that concussions require the loss of consciousness, though one can suffer from the symptoms of concussion without losing conciousness.[15] Vision disturbance, unconsciousness and loss of equilibrium are some possible symptoms of mTBIs.[3]

Each year, there are 3.8 million sports related concussions in the USA[3]. Each concussion occurs from different combinations of magnitude and location on the head. This causes each concussion to be different. Symptoms vary between incidents.

Symptoms may last minutes or days, show up immediately or become evident days after the incident.[11] That being said, concussions are particularly difficult to study and research. Researchers cannot agree on a proper definition of a concussion, causing research results to not agree between studies.

Eric Zemper studied the relative risk of concussion after being diagnosed with a previous concussion.[16] It is commonly assumed that that there is a greater risk of concussion when already suffering from one, but it had not been tested. He predicted that the relationship was directly proportional. It's a topic of interest because there is an on going search to determine what the long-term effects of multiple concussions are.

In Zemper's study, concussions were monitored over two year (1997-1998) using a national survey of college and high school players. The Athletic Injury Monitering System provided an accurate survey to represent the entire country. The data was gathered from the documentation of concussions by trainers around the country. From the data, Zemper projected there was 44,000 concussions per year due to football at the collegiate and high school levels. He found that the relative risk of concussion is 5.8 times greater after previously being diagnosed with a concussion.[16]

Zemper, however, used only concussions that resulted in loss of consciousness.[15] As you can see, the values that he calculated would be different using different standards. Concussions that occur without loss of consciousness can also be severe and cause lasting damage. The number of concussions per year would increase, and there could possibly be a change in the relative risk.

In an attempt to better understand concussion, research has looked into the underlying biomechanics that occur during an impact. This may help lead to the answer

to what specifically causes concussion. By understanding the kinematics of the head and brain, not only will the underlying cause be determined, but also possibly a threshold for what magnitude of impact the head can take. This will help with the design and improvement of helmets to better prevent concussion.

Biomechanics Of the Concussion

Though the methods of research have changed over the years, the results of concussion studies have found many of the same things. The overall consensus of the underlying cause of concussions is that there is a mixture of factors involved.

In 1948, Ward et al. performed a study to create a theory behind the physical mechanism of concussion.[15] Using pressure waves, concussions were created to form their theory. Their subjects in this experiment were decapitated cat heads with strain gauges implanted into their brain. Two types of waves were created, the first through the dropping of a weight at a known velocity onto the decapitated head. The second method was creating a percussion wave in water with the decapitated head partly submerged. By comparing the different mechanics that occurred during each test, Ward et al. hoped to propose a theory.[15]

The key to Ward et al.'s theory was the measurement of pressure inside the head. Both negative and positive pressure is present during an impact.[15] Negative pressure is when the enclosed area has less pressure then its outer environment and positive pressure is when the pressure inside is greater then outside. It was concluded that the damage to the brain during a mild traumatic brain injury was caused by negative pressure. Negative pressure causes cavitations or formation of air bubbles in the tissue. The cavities quickly

collapse and cause shearing of the brain tissue. This damage to the tissue will cause inhibition or paralysis of the nerves within the brain, leading to the symptoms one expects from a concussion.[15]

Modern technology has allowed recent studies to use less cruel methodology to study mTBIs. Many researchers have benefitted from the use of video analysis to reconstruct impacts within a lab using crash test dummies. Accelerometers and other sensors instrumented within the helmets and dummies have made studying impact kinematics much easier.

The pressure differences and shear stress that Ward et al. discussed are created from a mixture of angular and linear acceleration. Trying to find the underlying cause has stirred a debate over which acceleration has a larger role.[10] King et al. studied this controversy in their research.

Both linear and angular acceleration have supporting evidence to why they may be the main mechanism of concussion. Linear acceleration causes displacement of the brain as well as deformation to the skull.[10] The deformation changes the pressure gradient within the skull, causing intracranial damage. Another thing King et al. found supporting linear acceleration as the cause of concussion, is that research has found it takes twice the rotational velocity to produce the same impact as translational velocity.[10]

Angular acceleration's main argument is that it is the source of shear stress. Others, like Ward et al., found that shear stress/strain may be the source of the damage to the brain tissue. They found that the best predictor of injury is strain rate at the midbrain.[10] Most of the damage occurs at the midbrain, with little occurring at the surface. Also, helmets have modeled to reduce linear acceleration.[2] Impacts begin with

the deformation of the outer shell of the helmet. Deformation translates into the compression of the padded helmet liner. This reduces the linear acceleration on the head, but the final phase of the impact is the rotation of the head about the neck.[14] If linear acceleration was the main cause of concussion, there would have been a considerably larger decrease in concussion.[10]

King et al. made some conclusions from their work. Football impacts and collisions rarely consist of solely rotational or linear acceleration.[10] Both occur and may together cause concussion. Football helmets have been able to reduce linear acceleration, though not having any effect on rotational. That being said, concussions have not been completely eliminated by helmets, supporting that angular acceleration is involved.

Zhang et al. used video analysis, instrumented helmets and Hybrid III dummies to try and determine a threshold for brain injury.[18] Standards such as Head Injury Criterion (HIC) and the Gadd Severity Index (GSI) have been used in testing helmets. Such standards were good in the past when skull fracture was an area of concern with helmets. These standard are on a basis of linear acceleration, not angular acceleration. Since angular acceleration has been proven to be involved in concussion, these standards are no longer beneficial in preventing concussion. Zhang et al. hoped to discover a predictor for concussion that could be used as a new standard.

The kinematics gained from the video analysis of football collisions were used to model the impact using the dummies. Dummies were outfitted with nine accelerometers to measure head acceleration during impact. Head to head impacts were the only impacts modeled since they are the most common impact to cause concussion. Finite element was used to analyze the data they received from the impacts.[18]

Results showed that, again maximum shear stress at the brain stem had the highest correlation with being able to predict injury.[18] It was determined that brain contusions and hematoma were caused by changes in pressure within the skull, shear concentration and relative motion.[18] All of which are influenced by both angular and linear motion.

Viano et al. did more research on the biomechanics of an impact. Again, recreation of football impacts from video analysis was used. This study considered duration of impact and its effect on the heads response.[14] Thirty-one impacts were reconstructed in the lab, twenty-five of which were know to have caused concussion.

Again, results showed that the greatest strain, of about 52.6%, occurs at the midbrain, 16.4 ms after impact.[14] There is a significant amount of time between impact and peak strains, which brings up a question. What occurs after the impact, in the latter stages of the collision, that is causing this effect on the brain. Viano et al. also found that neck strength can help reduce the risk of concussion. Increasing neck strength decrease the head acceleration during an impact.[14]

The research done to better understand the biomechanics of an impact and the causes of concussion has helped do just that, however concussion rates still rise. As Zhang et al. stated, concussion rates are not decreasing, as they should be with the technologies we have today.[17] There is a better understanding of how concussions manifest, but unfortunately, it seems like not one specific thing causes it. A combination of accelerations, pressure differences, stress and strain all cooperatively affect the brain during an impact. Average accelerations and average magnitudes of force can be calculated, but with so many possibilities and situations for a person to be hit, it is

impossible to fully eliminate concussions. There will always be a risk for them, and a high risk at that.

The Mild Traumatic Brian Injury Committee (MTBIC), formed and funded by the National Football League, performed much of the research cited and stated previously.[2] A lot of work has been put into determining the biomechanics of an impact, but not until recently has the research translated over to helmet design and changing how the NFL works to protect its players. The NFL is a business looking to make money. With that in mind, decisions are sometimes made that may not have the player's best interest in mind. For example, injured players are sometimes hurried back onto the field before being 100% ready to help the odds of the team to win.[7] The MTBIC was instituted 1994, however it took until 2011 and an unfunded, independent study at Virginia Tech to establish a rating system for helmets based on their performance preventing concussion.[2] In the following section, the ethics and conflicts of interest within the NFL's policies on head injury over the years will be examined.

History of Helmets and Concussion Policy in the NFL

Helmet and Safety History

The first American football game was played on November 8th, 1969 between Princeton and Rutgers.[1] The rules during the first games were much different then what we have today. The game more resembled a mixture between rugby and soccer, but it is considered to be the origin of the sport we watch and play today. In the first years no equipment was used. This soon changed when it was realized how dangerous of a sport it could be.

Over the years, American football has developed to better protect the players. Equipment modification has been the major tool used to increase the safety of the sport. **Figure 1** shows a timeline of historical, helmet and head injury related events that have occurred in American football history. The first leather helmets were designed and used in 1893 during the Army-Navy game.[1] It was first made for a Navy player who was advised by a doctor that he would risked death or severe injury if he took another hit to the head[1]. Facemasks were introduced in 1935 and in 1940 Riddell introduced the first plastic helmets[2]. Since then, numerous modifications to the plastic helmet have been done to prevent injury.

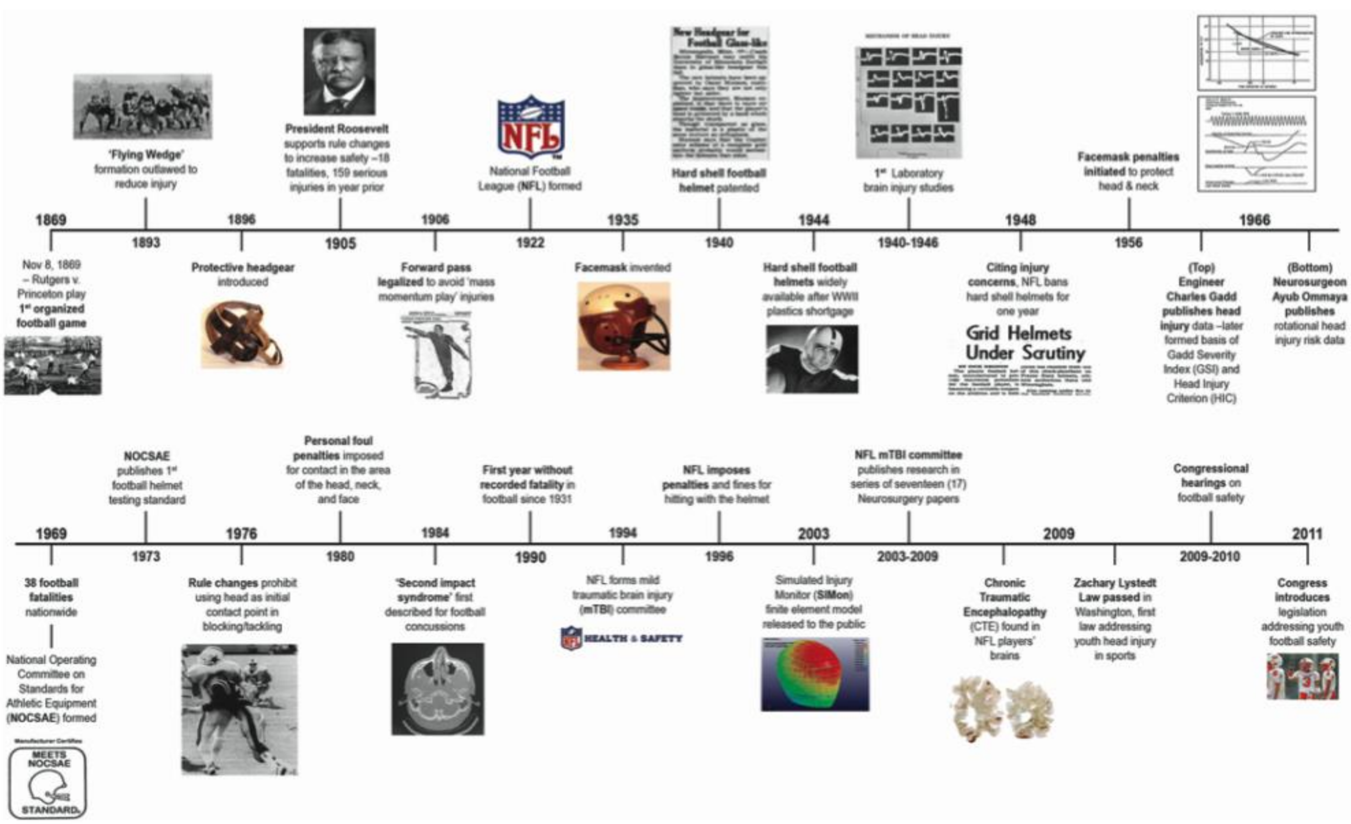

Figure 1 Timeline of historical, head injury related events in American football.[2]

Rule changes have also been key in lowering head injury risk. In 1905, 18 on field deaths lead to President Roosevelt supporting rule changes. In 1906, the forward pass was introduced to spread the game out more. After the introduction of facemasks in 1935,

facemask penalties were created in 1956. In 1976 and 1980, penalties outlawed hitting with the head and face when tackling and blocking. These penalties were taken a step further in 1996, when players began being given personal fouls, and in the NFL monetary fines for targeting an opponent's head when making contact. More recently changes to the game such as shortening the kick off length and disallowing wedge blocking during kick returns has helped reduce head injury. It has been noticed that a majority of head impacts and injuries occur during the kickoff.[2]

In 1922, the National Football League was created.[2] As a professional sport, one of its jobs was to mandate rules authorize changes that would not only affect its league, but also set a precedent for American football at all levels. Many of the rules listed above were created by the NFL and have shaped the game into what it is today. Aside from the on field changes, the NFL assisted in research and regulations off the field.

NOCSAE

The year 1990 marked the first season since 1931 that did not have a football related fatality.[2] It is daunting to think that each year up until 1990, a player died playing this sport and people continued coming out and playing knowing the risk. This decrease to zero deaths was in part due to the work of the National Operating Committee on Standards for Athletic Equipment (NOCSAE). During the 1969 season, 38 football related deaths lead to NOCSAE.[2] NOCSAE was created to set standards on helmets and set up a way to test a helmets ability to prevent injury. In 1973, NOCSAE came out with their first standard.[2] The standards were set up using the Gadd Severity Index (GSI) which is a severity index for head injury. It is based on the acceleration of the head

during an impact. It mainly uses linear acceleration, which is good for severe head injuries such as skull fracture but does nothing for concussions.[6]

In 2011, a study was done to compare impact tests of 21st century plastic, state of the art helmets with 20th century leather helmets. NOCSAE standards are set up to only test high magnitude impacts, and disregard the low dose, high frequency impacts that occur when players hit head to head[2]. Instead of focusing mainly on linear acceleration, Bartsch et al. also looked at angular acceleration, angular velocity, brain contusion, GSI, defuse axonal injury, and acute subdural hematoma. Helmets were tested using an instrumented and helmeted NOCSAE head and impacting it with another swinging helmeted head. Eleven modern helmets and two leather helmets were used in the study.[2]

Bartsch et al. found that the old leather helmets performed as well or better then state of the art helmets used today.[2] This proved that the old GSI system and NOCSAE standards are out of date and need to incorporate some new technology to be useful in the fight against concussion. After being created in 1973, NOCSAE standards have not changed. All helmets created by companies today pass the NOCSAE standards with ease. That’s because the only requirements that helmets must pass is to just simply the prevent skull fracture.[6] This is no longer the issue at hand with helmets. Concussion is the topic NOCSAE should now be researching and setting up standards for and it has yet to be done.

NOCSAE issues standards on all sporting equipment. Anywhere from football gloves to youth baseballs, NOCSAE must approve before the equipment is sold and used on the field. That being said, every company that produces these products must pay licensing fees to place the NOCSAE logo on their equipment.[6] If new standards were set

up testing for concussion, some helmets in circulation now would not pass these concussive requirements. If standards were created, any helmet manufactured before 2007 would be considered hazardous to use.[6] That means the helmet would not be able to wear the NOCSAE approval, and the company would not paying NOCSAE. Hoping to not lose income, the NOCSAE has stayed put on the issue. This has in turn made the NFL look bad. Players have looked to the NFL to issue safety standards. Since the NOCSAE has yet to make recommendations, the NFL allows the players to choose on their own.[6]

It is also tough for the NFL to mandate players to use certain helmets because so many factors go into a concussion. Some players may use some of the worst rated equipment and never suffer a concussion, while others are more prone to it. Helmet styles fit differently from person to person. Veterans in the league would not take kindly to being told what type of helmet to wear if they have been doing things their own way for years.[6] To be able to mandate helmets, first a rating system must be created which will be discussed soon. Secondly, colleges and universities must mandate these safer helmets and accustom the players to them so when they pass on to the NFL, these are the helmets they wish to use.

NFL Traumatic Brain Injury Committee

Another issue facing the NFL and players are the long-term effects of concussions. Little is known, or proven, about the affects concussion has down the road for players. All evidence suggests that concussions have some serious consequences, though the NFL denies this. Zemper showed that just over two years, it could be proven that one concussion can significantly increase your chances of receiving another

concussion. Adding up concussions over the course of an NFL career must have some affect.

Many popular players have had to cut their careers short because of head injuries, while there are some others who did not, but probably should have. In recent years, a pattern has developed of players committing suicide whom have had a history of head and brain injuries. Andre Waters and Junior Seau both died from self inflicted shotgun wounds. Waters brain, at 44 years of age, resembled that of an 80-year-old Alzheimer's patient. Before he died, he claimed to have lost count of his concussions at 15.[7]

Another popular, but sad story is that of Mike Webster. After 17 years in the NFL, Webster had lost control over his body. He suffered from dementia, which was a result of the deterioration of his brain. At times, he was in so much pain he sometimes was unable to go to sleep at night. "Sometimes, the only thing that brought him relief was a black taser gun. He would ask [his ex-wife] Sunny of his son Garrett to stun him into unconsciousness."[7] Once a millionaire, his dementia lead him to become homeless for the last 5 years of his life.[7]

The issue here is the NFL's policy toward brain injury and the support to its players after retirement. Retirees feel that the NFL players association abandons them after retirement. This is linked to the NFL's feeling that concussion has no long-term effect on players.[7]

With the rising concern for mTBI's during the '90s, the NFL created the Mild Traumatic Brain Injury Committee to research the biomechanics and causes of concussion.[2] Most of their work was explained previously in the work done by Viano et

al., Zhang et al., and King et al. As stated, their work provided insight on how concussions occur, but were conflicted, having been funded by the NFL.

For years the NFL has instated a culture that has put the health of its players at risk. Owners and coaches pressure players to return to the field after injury as soon as possible. This is particularly dangerous in the case of concussions because of nature of the injury. It is not well known how much time a player should take to recover from head injuries.[11] Team physicians also do not help because the NFL teams pay them. Some star players have a direct impact on the chances of their team winning a football game. Physicians are conflicted to return players to the game because if they do not do what the owners and coaches wish, it could cost them their job.[7]

The work done by the NFL's MTBI committee also is biased towards owners and coaches. They have seen recent criticism for claiming there is no proven long-term effect of concussion and insisting that players were safe to return to playing the day of the injury. People claimed that the group ignored studies that proved these statements were not true.[7] Eventually, this caught up to the MTBI Committee, causing the lead researcher to step down from its position. Later, NFL commissioner Roger Goodell ordered to committee to expand its research.[7]

Conflicts of interest in the past have restricted research and the ability to actually help protect players. Information in recent years has forced the development of new techniques in concussion research. At the forefront of this research is the Bioengineering program at Virginia Tech. Their work with football helmet testing has opened new doors for concussion research.

Helmet Research

The development of a helmet rating system that directly rates helmets on their ability to prevent concussion seems to be directing the field in the right direction. Conflicts of interest have caused NOCSAE to halt their research and development of standards based on head injury. This has left Virginia Tech to do NOCSAE's job and push concussion research forward.

Virginia Tech's research is not funded by the NFL or helmet manufacturers. This leaves them unconflicted and interested solely in the well being of the players.[6] It has begun an era of research in which equipment is tested and actively designed to prevent injury. At the base of their research is the HIT System.

The HIT System has allowed concussion research to move away from recreation of impacts using dummies and has allowed the field of play to become the laboratory. Football helmets are instrumented with accelerometers to measure the linear and angular accelerations of the head during on field impacts.[5] This data from the impacts are then transmitted off the field to be analyzed. From the data, patterns of what positions are more susceptible to concussion impacts and during what plays these are more likely to occur can be made.[5] This has lead to the development of the STAR evaluation system for football helmets.

The first step in creating an evaluation system was to look at the head impact exposure of football players. Crisco et al. put together a study to quantify this exposure to head impacts.[4] During the 2007, 2008, and 2009 football seasons, 314 players were instrumented with the HIT system an observed. Impacts were quantified by magnitude,

location, and frequency. Each player was categorized by position and impacts were recorded during both practice and games.[4]

The first step to this study was determining how to quantify impact magnitudes, locations and frequency. Magnitude was quantified by peak linear and angular acceleration. Accelerations below 10 g's were disregarded to eliminate non-impact accelerations.[4] Location of impact was determined by the HIT System and categorized as front, back, side or top of the head. Frequency was quantified as the number of impacts that occurred during a team session, which included both games and practices. Another parameter measured was the likelihood of injury. This was computed in HITsp, which considers both magnitude and location of the impact. This allows a measure of impact severity for each impact.[4]

The results of Crisco et al.'s work determined that player position has the greatest effect on the exposure of a player to head impacts. Quarterbacks and running backs received the highest magnitude of hits, though the frequency of hits was relatively low. On the other hand, linebackers, offensive lineman and defensive lineman received the most head impacts, but they were at lower magnitudes.[4]

This study was then used to help Virginia Tech develop its Summation of Tests for the Analysis of Risk (STAR) evaluation system. Though head accelerations are indicative of head injury and response, there have not been any analytical methods to evaluate helmet performance with concussion.[12] All prior evaluation standards created by NOCSAE were taken from drop tests measuring just linear accelerations. Rowson et al. proposed an equation that could calculate the relative performance of football helmet

models by relating head impact exposure to the injury risk of each impact. The equation is shown below:

$$STAR = \sum_{L=1}^{4}\left(\sum_{H=1}^{6} E(L,H) \bullet R(a)\right)$$

Each helmet was put through series of twenty-four drop tests using a NOCSAE drop tower. Each drop test would correlate to a different impact a player would be exposed to each season. It used six different heights (*H*) and dropped on four different locations (*L*) on the helmet (front, side, back, and top). *E* represents the head impact exposure. It was determined using the work done by Crisco et al. The chances of being hit on each location around the head were turned into a percentage. *R* represents the injury risk as a function of the peak acceleration, *a*.

The result of the equation assigned each helmet numeric value that correlated to the helmets ability to prevent injury. This value was correlated to a five star rating system; five being the best available and no stars being not recommendable. The results of testing ten different helmets is shown below[8]:

Five Stars: Best Available
- Riddell Revolution Speed

Four Stars: Very Good
- Schutt ION 4D
- Schutt DNA Pro +
- Xenith X1
- Riddell Revolution
- Riddell Revolution IQ

Three Stars: Good
- Schutt Air XP

Figure 2. Riddell's Revolution Speed, the highest rated helmet in Virginia Tech's STAR Evaluation System (riddell.com)

Two Stars: Adequate
• Schutt Air Advantage

One Star: Marginal
• Riddell VSR4

NR: Not Recommended
• Adams A2000 Pro Elite

This provided the first model-by-model rating system that players could use to see what helmets best-prevented concussion and head injury.[6] As expected, it was met with criticism. Helmet companies don't want easily understandable safety information about their equipment and the NOCSAE oppose the ratings, urging players to get all information on risks and safety from the stickers on the helmet. Gregg Eastbrook's comment on Virginia Tech receiving disapproval, "That Virginia Tech is upsetting the establishment surely means the school is making an important contribution."[6]

It seems the work done by Virginia Tech has raised awareness on the faults of the previous policies and has shed light on what the future might hold for concussion prevention. Virginia Tech still uses the HIT System during practices and game. Hit magnitudes are monitored by physicians on the sideline. If a hit magnitude reaches a certain threshold, the program immediately notifies the physician and the player is evaluated before returning to the field.[6] This may be the beginning of a change in football culture. In the past, concussions were underreported. Players and coaches alike pretended that nothing happened. Now, these head impacts may not be able to be passed over as easily.

Senior Project

The basis of my senior project this year was to design and construct a laboratory exercise that will be used by the bioengineering department in their biomechanics courses. Improvements were made on an apparatus that had been previously designed for a sophomore research project. The apparatus was designed to recreate an impact with a magnitude similar to that of a concussion inducing hit in football.

Motivation

Concussion research is an interesting topic and makes for an interesting laboratory set up. This laboratory will allow students learn and examine a topic they have directly heard of or seen in the news, or even dealt with themselves. Also, with it becoming such a prevalent issue, the field of concussion and head injury research is growing. Recently the National Football Association has begun working with General Electric on head injury research. Introducing these bioengineering students to this field may help stear them towards a working field they did not know about.

The bioengineering department and program is growing at Union College. Introductory biomechanics course have been instated just within the past two years. Because of this, biology specific biomechanics labs have yet to be developed. Mechanical engineering labs are being used to teach the material. This concussion laboratory will help the department become even more independent and my project will be beneficial for years.

Initial Design

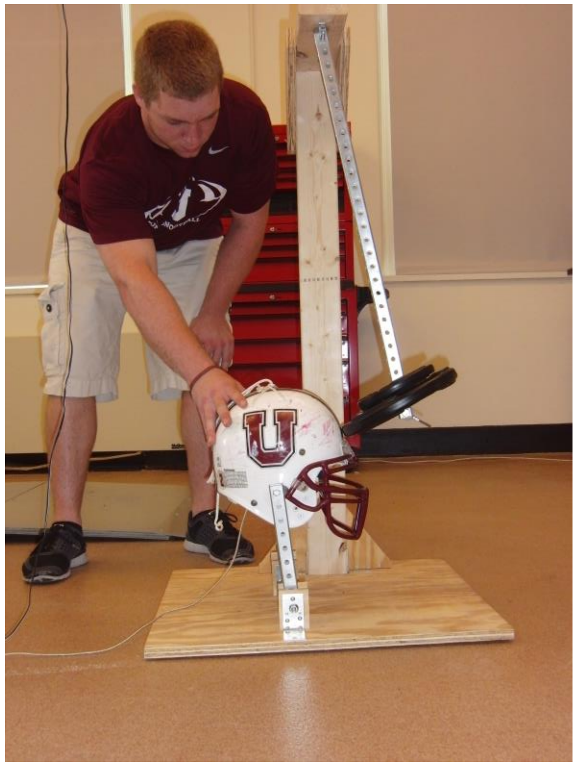

Figure 3 Initial design of the laboratory apparatus

The initial design of the experimental apparatus was constructed during my sophomore research project. An image of the design can be seen in **Figure 3**. Though the set up did have many complications when testing, the overall idea and mechanism of a swinging pendulum was kept for the final design. The main idea is that from the length of the arm and mass of the pendulum, the impact that occurs when the pendulum hits a head form will be equivalent to that found in a head to head football impact. As stated previously, there are many situations in which a concussion will occur. This set up was designed to give a basic example, mimicking a direct blow to the head. This would likely

be from the head of another player. With concussions occurring at a range of forces, an approximation from research articles was used as the impact. From this impact the proper measurements of the apparatus was calculated.

The biggest issue with the original design was the material that the apparatus was made of. Plywood and 2x4's were used to make the frame of the apparatus. This became an issue because of how each of the components was connected. With a big impact and swinging of a weight, the nails and screws became loose. Also, because the wood is very light in weight, the swinging arm caused the whole apparatus to shift upon impact. One final issue with using wood was that the measurements and dimensions were not precise. The wood was warped and became worse during the testing.

The design of the apparatus also caused problems. Only one vertical member was used to support the arm. This was an issue because the weight of the arm caused a moment that contributed to the instability of the wood. After a few uses, the whole vertical aspect of the apparatus had a bend to it.

The pendulum arm was another major issue in the initial design. Both the point at which the arm swung and the point of impact caused problems. The hinge that the arm swung upon did not keep the arm in line and allowed movement horizontally. This is not desirable because the impact needs to be focused at a single point and moved within the sagittal plane. Also, free weights were used as the weight at the base of the arm and held on by a single pin. The weight supplied the main source of impact, but because the weights were free and shifted, they did not impact at one point and did not stay straight, occasionally becoming stuck in the facemask.

The final aspect of the apparatus that caused issues was the headfrom A lot of time went into trying to figure out what would be used as a headform, both in the previous and current model. It is the most important aspect of the apparatus as it is the part that is being impacted. It also has to be able to fit the football helmet. In the previous model, different set ups were experimented with such as springs and rods for the neck and a Styrofoam or plastic mannequin head forms for the head. These materials were difficult to connect together, and the head forms would not have withstood the impact. Ultimately we could not mimic a neck and had to resort to the set up shown in **Figure 3**. This posed problems because it could not fully support itself and had to be held up before impact. It contained two rods that connected on each side of the helmet at the ear hole. Each rod connected to a spring that provided some stiffness, but because the construction was last minute, proper calculations weren't made. There was no head itself. Weights were used and tied into the helmet to give it an approximate mass of a human head.

Overall, the original set-up needed a lot of work before it was ready to be used in a classroom setting. The original results also showed this. Video analyses of the impacts were erroneous due to the rocking of the whole test set-up and the accelerometers used in the helmet kept falling out during the impact. A better, more durable set-up was modeled during my senior project.

Project Goals

The goal of this project was to create a lab setup that introduced students to the topic of concussions, and the biomechanics behind them. It also would provide a laboratory that would demonstrate concepts learned in the classroom. To do so, the

laboratory would be broken into two parts. The first would be a section introducing the topic of concussion to the students. The second would require the experimental set up and exercises using the set up and the material from the class. The first and major step to doing this was to design and construct a fully functioning lab set up. From this, it would be possible to test and construct a lab around it.

Constraints and Metrics

There were issues that had to be kept in mind when constructing a setup or apparatus that would be used in a classroom. The first was that it must be durable and withstand repeated testing. This required that the set-up be made of the proper material. This also includes that the apparatus had to be able to withstand the swinging pendulum and impact that occurs. At the same time, the apparatus had to be lightweight and able to be transported from classroom to classroom, then stored when not in use. Another thing that should be addressed is that the apparatus should be at eye level when in use. The previous model was hard to work with and manipulate because it was on the ground. The new set up had to be either built to eyelevel or be able to fit onto a table and attach so the motion doesn't move the apparatus.

Final Design

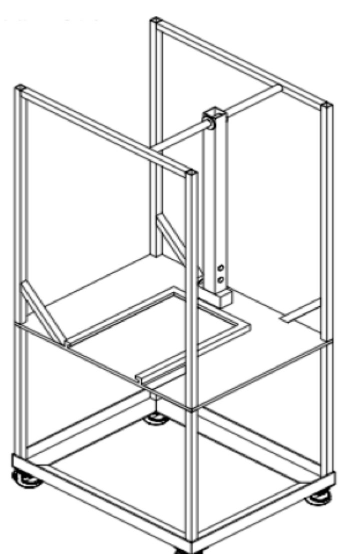

Figure 4 Final design of the laboratory apparatus

To account for all of the changes that needed to be made and account for the constraints, a final design was created using Solidworks. The final design is shown in **Figure 4**. Instead of wood, the set up is made of steel. Steel is an inexpensive material to work with, and can easily be welded to create this set up. Also, the hollow square tubes that it is made out of keeps the weight relatively low and easy to maneuver. To adjust for stability, instead of one vertical member, four were used. These were spaced out far enough so that the full impact could be recorded using a high-speed video camera. Each of the four vertical members is braced with diagonal pieces in the sagittal plane. This is the same plane in which the arm rotates and the impact occurs.

Another aspect of the new design is that legs and wheels were added for mobility and height. This adds to the maneuverability of the setup. Also, the legs give the set up a height that will be easy to work with. The lengths had to allow the set up to pass through the height of a doorframe, so the total height was kept under six feet eight inches. The wheels used are casters with leveling pieces so that the apparatus is not moving around when in use. The bottom of the apparatus also allows for the addition of another platform on which other materials such as cameras can be placed if needed by the professor.

A new design of the pendulum was formed that would properly strike the headform during the impact. The design was modeled after an example shown in **Figure 5**. A rounded edge

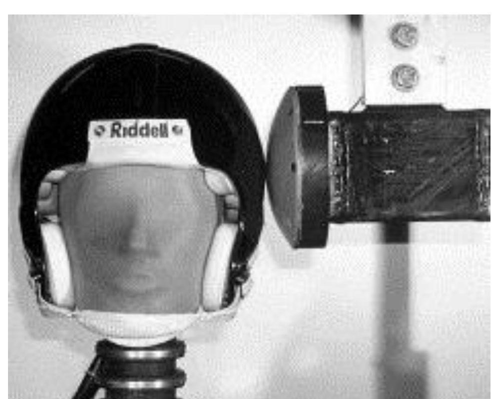

Figure 5 Example of pendulum weight design from sciencedirect.com

placed on the front of the weighted part delivers the impact at a concentrated point. The weight behind the rounded curve will have to be adjusted once the final model is built to ensure the proper impact.

The last aspect of the apparatus that was addressed was the headform. The difficulties that arose in the previous model needed to be addressed with an actual head with a singular flexible neck that closely resembled the characteristics of an actual human head and neck. This would provide proper accelerations and movements upon impact, giving the best model. It was decided that a Hybrid III 50^{th} Percentile head and neckform would be the best choice considering that it is commonly used in similar impact testings. This would have the same characteristics as a human head and be able to withstand the impacts that would occur during the lab. A Hybrid III 50^{th} Percentile head and neckform was purchased from Humanetics ATD. A similar model is shown helmeted in **Figure 5**.

A complete set of drawings for the lab set up can be found in the Appendix. These were created using Solidworks. It displays all the aspects mentioned above in greater detail. Also, from Solidworks, the weight of the apparatus, if made of steel, was calculated to be 193 pounds. This is a reasonable weight to maneuver when on wheels.

Additional Aspects

While designing the set up, some other aspect were discussed and incorporated into the design. The first is a mechanism is to allow the headform to rotate. This will allow for the comparison of the effects of impacts at different areas of the head both from the helmet and the heads standpoint. The head sits on a plate that is able to slide in and out of the main apparatus. The plate and its corresponding part that it slides into are

square which allows for rotations of 90 degrees. This will allow for impacts to the front, side and back of the head/helmet.

Another aspect that will be incorporated into the design is a protractor next to the arm. This will allow for different magnitudes of forces, which can be incorporated into the lab exercise. Students will use their course material to predict how the different angles will affect the impact. This was not incorporated into the Solidworks design though the rotatable head was.

Future Plans

The remainder of this project will require another semester and an independent study. The actual model is currently in the process of having its parts purchased and then fabricated in the Union College Machine Shop. Another difficulty that is holding back the process is that the headform requires a 22-week lead-time. Measurements of the head and neckform are not attainable, which is an important aspect when calculating the arm length and weight for the impact. A mock headform is going to be used to do preliminary testing's for the lab. While the preliminary testing occurs, the actual laboratory exercise will begin to take form. An outline of the laboratory write up is shown at the end of the Appendix.

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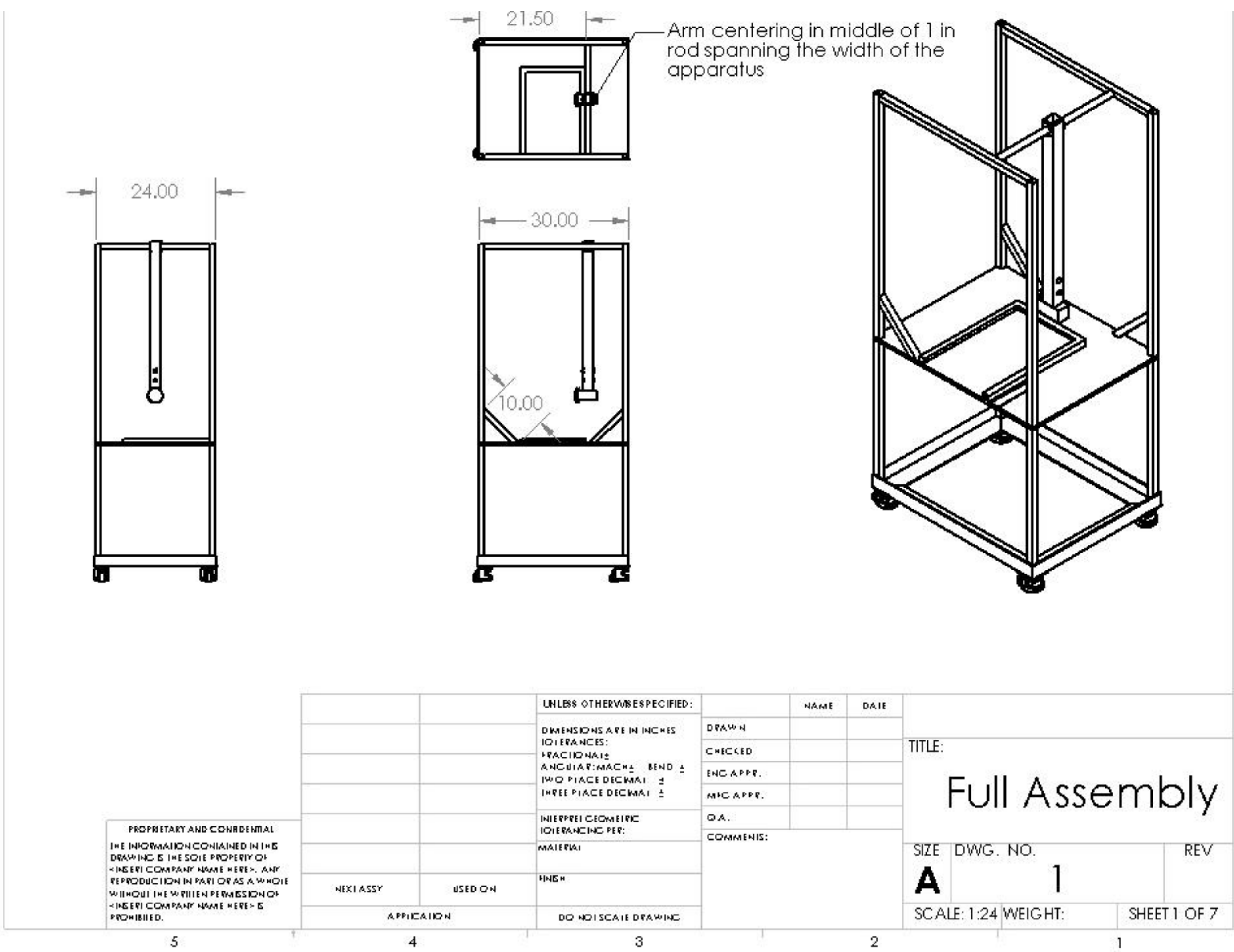
Appendix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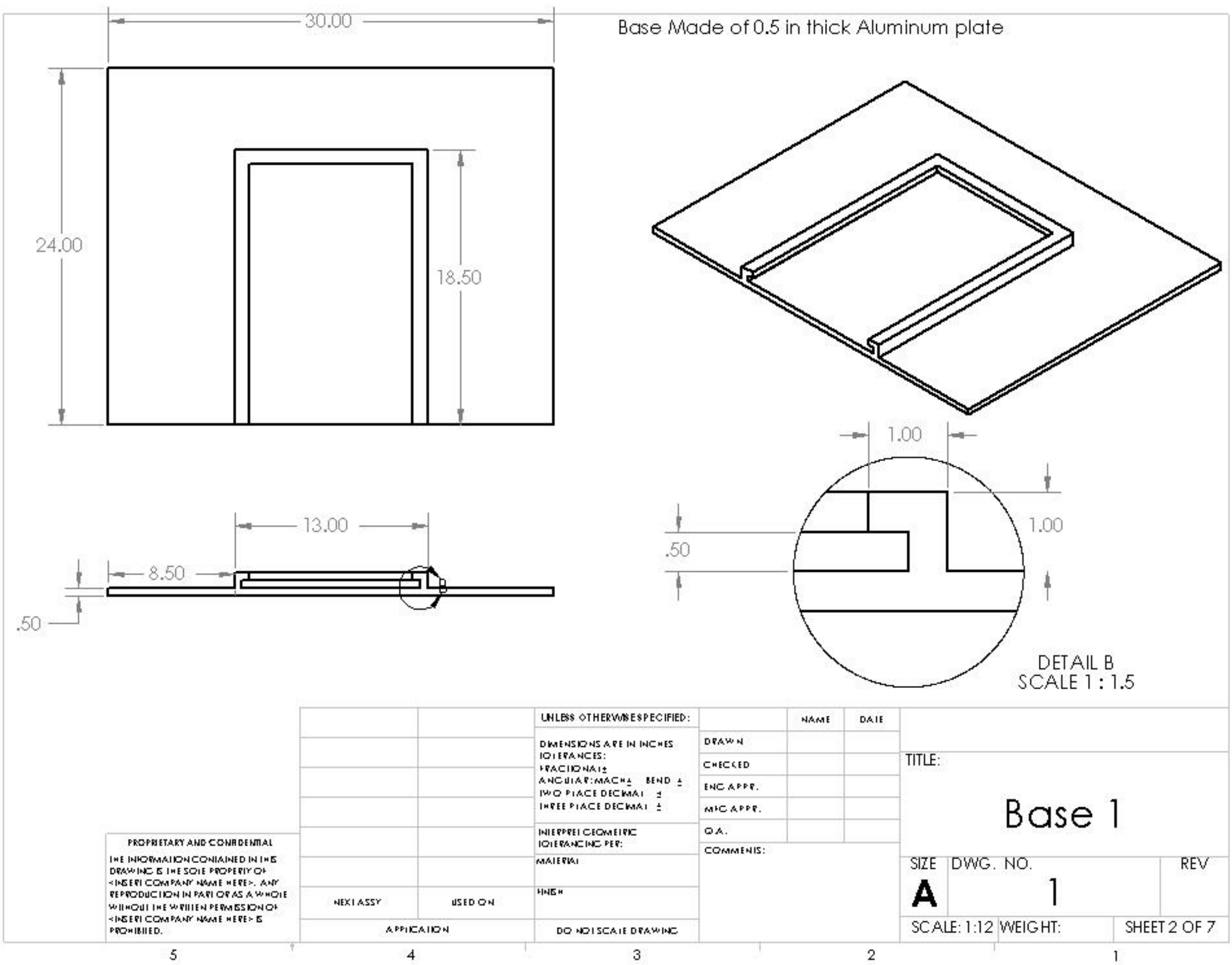
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Base Made of 0.5 in thick Aluminum plate
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DETAIL B
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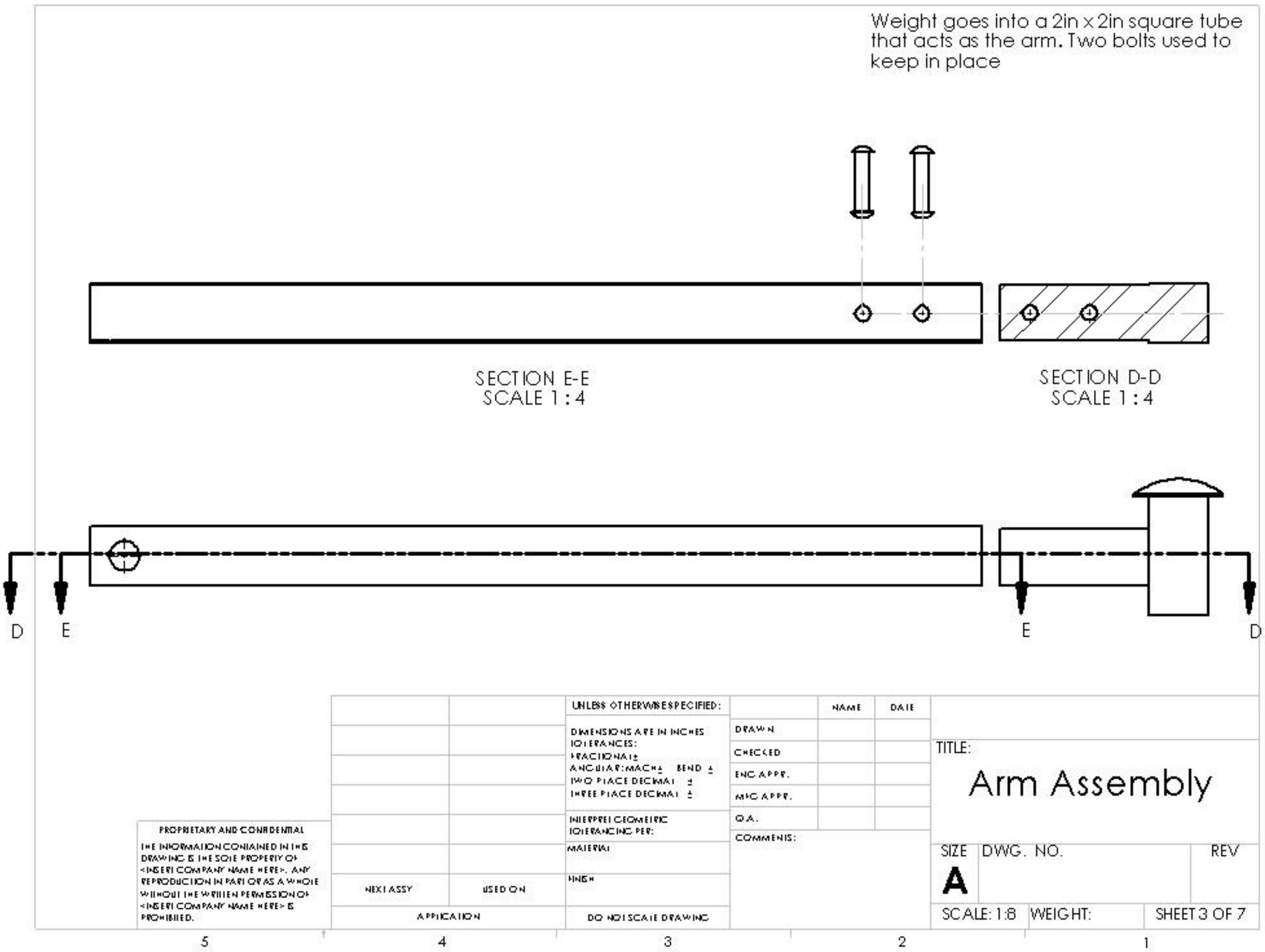
Weight goes into a 2in x 2in square tube that acts as the arm. Two bolts used to keep in place
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SCALE 1 : 4
SECTION D-D
SCALE 1 : 4
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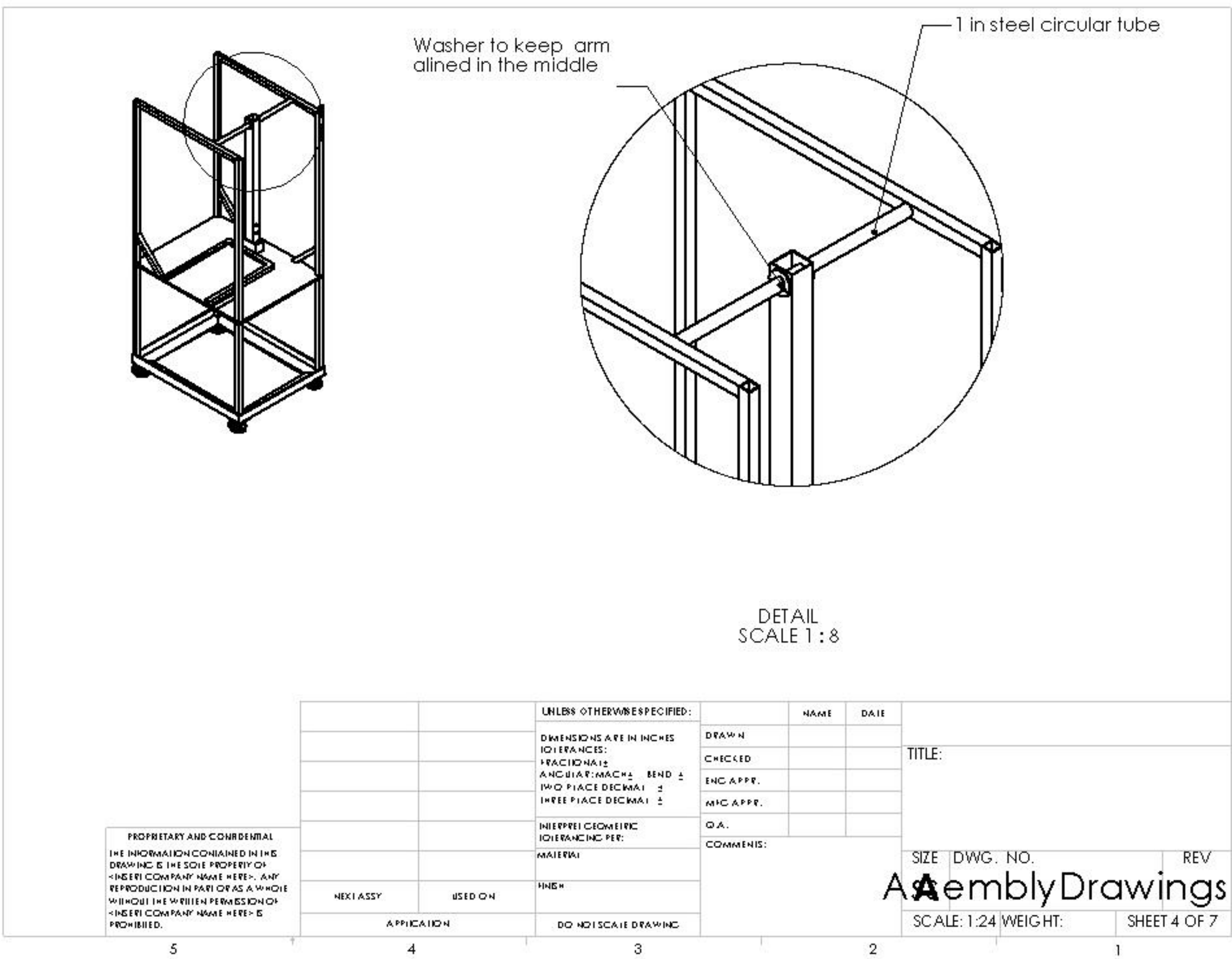
1 in steel circular tube
Washer to keep arm alined in the middle
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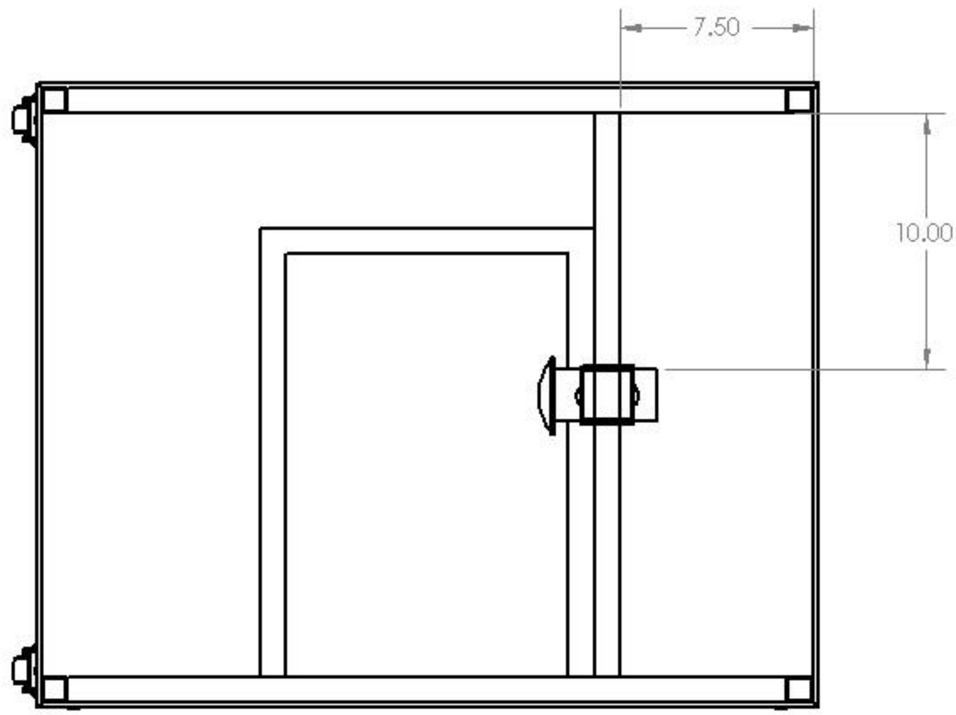

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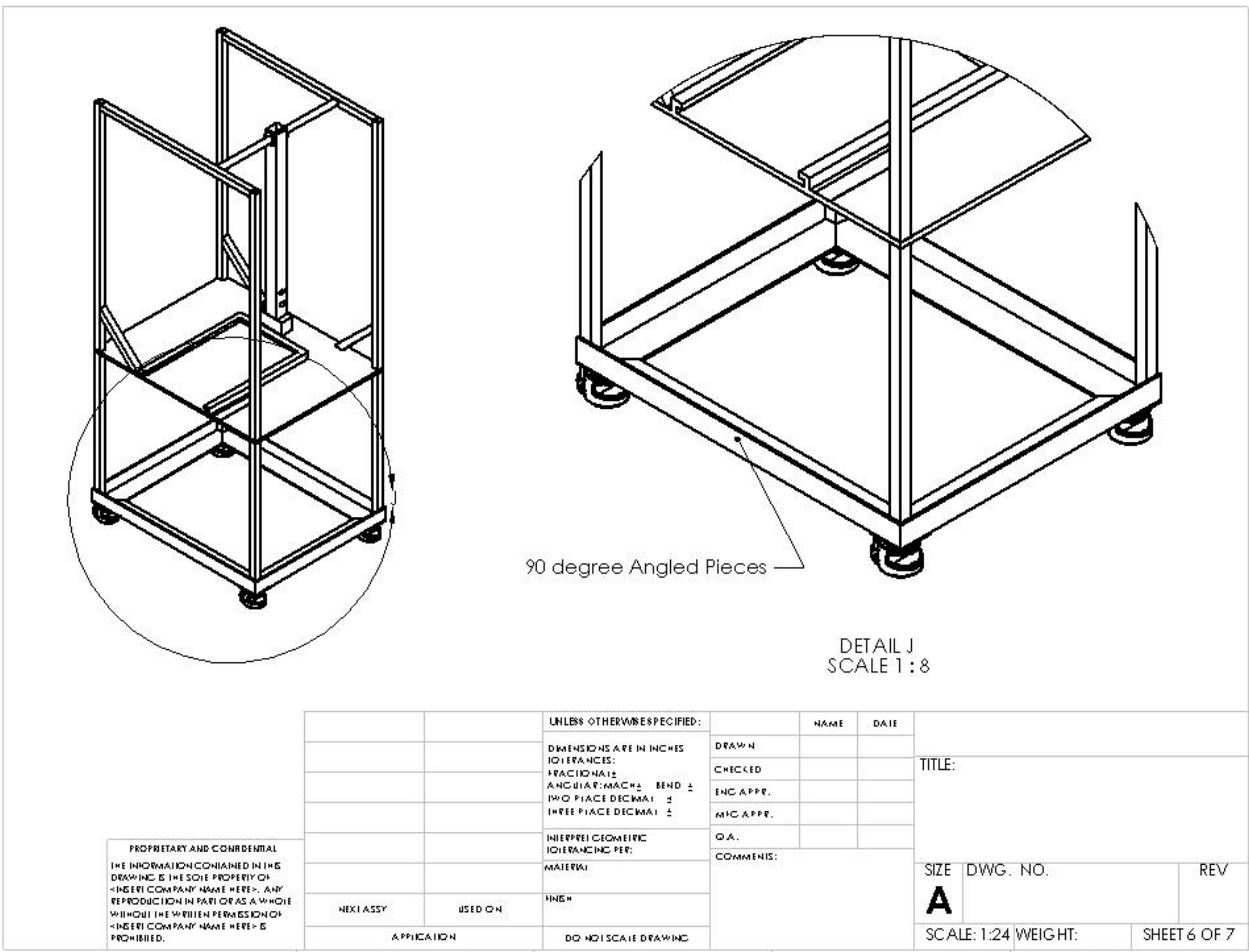
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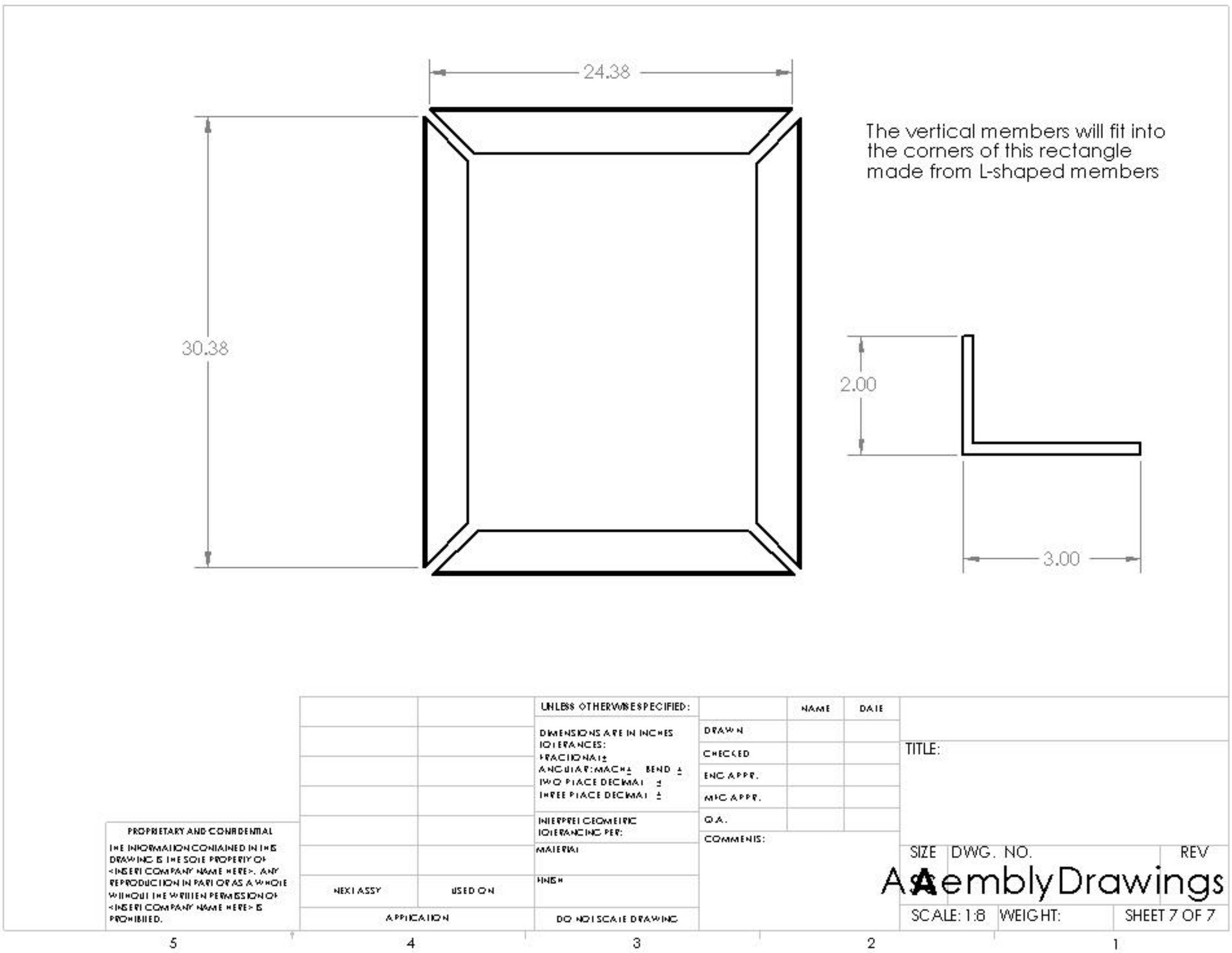
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The vertical members will fit into
the corners of this rectangle
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Lab Write Up Outline

- **Introduction**
    - **Written from the beginning of this paper to give background on concussion and its importance**
    - **Supply the article "A New Biomechanical Predictor for Mild Traumatic Brain Injury- A Preliminary Finding."**
        - **Introduce the biomechanics of concussion**
        - **Require a summary write up**
- **Part 1: Preliminary calculations**
    - **Theoretically calculate the force and accelerations from the lab set up measurements**
    - **Theoretically calculate how the magnitude of the force will be affected at different angles; write down angles**
    - **Write how a rotation of the head might change the impact magnitude**
- **Part 2: Video Analysis**
    - **Put headform through each of the different situations that were discussed in the preliminary calculations while filming using a high speed camera**
    - **Use videopoint to determine accelerations of the head and use it to calculate the force**
- **Part 3: Lab Report**

- **Use the findings and results to discuss what you found out about head impacts**