Force Measuring Helmet
Abstract

Head injuries have always been a menace for recreational sport, and now growingly for commuting cyclists. Skiing for example, where a quarter of all injuries after collision are to the head; or more broadly, cycling, which produces the most injuries each year, show that head injuries are on the increase. Thankfully, the use of helmets is increasing, reducing the risks of injury. Unfortunately, helmets are not always successful in reducing the damage - a notable example being Michael Schumacher, who went into a coma following a ski accident even though he was wearing a helmet.

Doctors who assess patients after collisions usually have no idea what is the strength of the blow, which could vary anywhere from mild concussion to more traumatic injuries. Therefore, I decided to invent a device which would be present on helmets to indicate the strength of a blow. The aim is to supply doctors with information of the crash so they have a clearer view on treating the patient.

Firstly, I did some research to learn in detail the role of helmets during injuries and a method for measuring the force of impact during an accident. Discussion at Imperial College, London with Dr. Ghajari on helmet designs and Dr. Dickenson on brain trauma revealed the importance of wearing a helmet and a key fact: helmets are no longer reliable after only one hit. This is due to the deformation and damage of the protecting polystyrene interior.

From this information I decided to design an electronic device that would measure the force of impact using force sensitive resistors and accelerometers connected to an Arduino Uno. This device would indicate that a helmet had suffered a strong blow and hence should no longer be used. After coding and experimenting, the electronic device appears to have shortcomings; firstly, there is an issue of battery life, secondly its size is large to fit discretely on a helmet, and lastly, the price remains too expensive to have for the mass market.

Therefore, I decided to make a mechanical version, which would not have the problems of the electronic version yet still be as accurate. I started with a proof of concept, an enlarged version of the final device. The mechanics of the device are very simple. A centre module with a defined mass has two elastic bands on it from either side attached to a frame. When hit, due to the inertia, the mass will slide, and will click in a ratchet system, rendering it unable to move. The first prototype proved successful, but had a major design flaw. The elasticity of elastic bands greatly varies with temperature.

For the second prototype, I decided to use compression springs whilst at the same time attempting to miniaturize the device. This proved difficult as the centre module could not be smaller than a certain size or smaller than a certain weight. Similarly the springs could only be specific widths and lengths to measure the required g-force, whilst still remain 3 cm long. In the end I managed to make a device just 11 cm long. Thanks to understanding the mechanics of springs I was able to produce a device which could house springs of different thicknesses, thus the possibility of measuring multiple g forces.

To prove that my device worked I developed a test rig based on one I saw at Imperial College. I was able to demonstrate that the required force set off the device.

In conclusion, the second device proved successful. In the future the device could potentially be curved for a svelte look on the helmet.
Introduction

Head injury is the leading cause of death and disability in people aged under 45 in developed countries, mostly resulting from falls. Skiing is a prominent example, where a quarter of all injuries after collision are to the head. Head injury is also a growing issue for commuting cyclists who produce the most injuries each year (cycling is becoming more popular method of transport). These statistics show that head injuries are indeed on the increase.

Thankfully, the use of helmets is increasing, and the awareness towards head injuries is also on the increase. All these factors are useful in reducing the risks of injury to the head. Unfortunately, helmets are not always successful in reducing the damage. A recent example is that of Michael Schumacher, who suffered serious brain damage following a relatively minor ski accident even though he was wearing a helmet.

I have personal experiences which lead to my interest in this subject. Two years ago on New Year’s Day, I had a ski accident with my father where at high speed I went into him and he landed on his head, cracking the helmet, and knocking him unconscious. A helicopter had to come to take him to the nearest hospital, and I didn’t see him or know how he was until the next day. Fortunately it was just a minor concussion. I realized on the other hand, that head injuries are not a joking matter, and that there is a flaw with current helmets: Doctors who assess patients after collisions usually have no idea what the magnitude of the blow to the head was, which could vary anywhere from mild concussion to more traumatic injuries.

Doctors should be able to know straight away what sort of impact they are dealing with on the helmet. This helps them understand the gravity of the situation. This made me think, why isn’t there a similar device on all helmets already, from cycling to ice hockey?

From this, I decided to invent a device which would be present on helmets to indicate the strength of a blow to the head. The aim is to supply doctors with information of the crash so they have a clearer view on treating the patient.

But before designing the product, I decided to do some research on what happens in head injuries, and what testing methods currently exist for helmets. Does a way of preventing head injuries already exist?
Whilst I was at an Imperial College Science fair, I was able to ask leading research scientists in the field of TBI (Traumatic brain injuries) for information. In particular, scientists at the fair explained how they had recently discovered that Xenon gas protects the brain after head injuries. They found that xenon, given within hours of initial injury, limits brain damage and improves neurological outcomes in mice both in the short and long term. “Although Xenon is chemically inert, this does not mean it is biologically inactive. Xenon has been known to have general anesthetic properties since the 1950s. Previous studies at Imperial have found that xenon can protect brain cells from mechanical injury in the lab.”

To learn more about the effects that an injury has on the brain I met Dr. Robert Dickinson of the Department of Surgery and Cancer at Imperial College, who had led the study on Xenon. I learnt that in fact, **after a blow to the head, most of the damage does not occur immediately, but in the hours and days afterwards.** What happens after a blow is that the brain (from inertia) moves within the skull hitting the surrounding bone. If sufficient hard, the brain cells near the site of the physical blow are torn apart and spread chemical agents used normally as messengers to go where they please. This results in an overloading of receptors on neighboring cells, and spreads, fundamentally killing the brain cells from inside out. Much like rot on a bruised apple, the chemical receptors spread, kindling a damage cascade that continues to grow- a rot spreading injury through the brain. So the **overall injured area of the brain is significantly larger than the area of impact.**

At present no specific drug to limit the spread or major burden of lesions of the secondary injury exists. Xenon, however, binds well the brain cell receptor (the NMDA receptor) and acts as a neuro protectant (protects the brain cells).
This explanation underlined the importance of being aware of the magnitude of blow that a person might have suffered to the head – and having this information rapidly.

Whilst at Imperial College, I also talked to Dr. Mazdak Ghajari of the Department of Aeronautics, who has been doing significant research in the last few years on helmet design. He explained the importance of wearing helmets. Some 1.5 million patients are diagnosed with traumatic brain injury each year in the U.S alone. In addition, there is a correlation with spinal cord injuries, where there are 1 million each year in the U.S. In these cases, the helmet makes an enormous difference not only to protecting the brain but also the neck and the spine.

There are two fundamental elements in helmets that enable them to decrease the impact on the head: the outer shell has to be strong plastic to protect the head, but underneath that, there must a significant polystyrene liner. This liner, when under extreme force, destroys the structure of the polystyrene and crushes it, thus absorbing the force of the blow. It is the liner that makes the difference between having a helmet, and not having one.

These observations lead Dr. Ghajari to conclude that in fact, once a helmet has suffered blow which may have deformed the internal structure of the liner (i.e. after an accident) the helmet is no longer useful at protecting the head. This implies that a helmet has a limited usage, and that must be replaced after a strong impact. This provides another motivation to measure the impact to a helmet since it can indicate that a helmet can continue to serve its purpose.

Dr. Ghajari and his colleagues have also been innovating a new way of testing helmets. Currently, helmets are tested only with a linear force (i.e. straight blow from the sides, front and back). Dr. Ghajari believes that that during an accident there are more factors: Firstly, the angle that head lands on is very rarely 90°, secondly, the body is usually moving when it falls, creating more of an inclined skid when head hits the ground. Lastly, the recoil and twisting of the neck generate rotational forces that have implications on the net force on the head. Dr. Ghajari and his team have been able to demonstrate that the mentioned factors do in fact have an effect on the magnitude of the impact to the brain. Since then new ways of testing helmets for the market have been developed, like dropping helmets on an inclined surface, and dropping helmets on moving surfaces to replicate motion.

I also decided to investigate if there was a scale to which head injuries are based (i.e. a specific force that is needed to generate concussion or more traumatic injuries). I found out that there is no actual defined force needed for concussion, as it can happen at multiple g-forces, yet averages from many incidents have indicated of the order of a 55 g-force threshold.

The general conclusion of this research is that helmets are extremely important, and in its respective sport helmets should always be worn as they greatly reduce the impact on the brain. As explained, a small impact area can actually give way to a large affected area of the brain. In addition, the most important part of the helmet is the polystyrene liner, which when deformed in a collision, means that the helmet is no longer valid after the accident.

All my information from Imperial College has been written with the aid of internet research to explain in detail. Furthermore, I have included all the links to the all the sites and all of Imperial College related papers, particularly Dr. Ghajari’s research papers and work on helmets in Annex 1.
Method

With the aid of my research I decided to start developing my project: a force measuring device to be put on a helmet. I started by looking at an electronic solution.

1. Electronic Model

An electronic device that is put on the helmet measuring the force of the impact seems appealing, as it is can yield very accurate results. After doing some research I realized that the best way of doing this is with an Arduino Uno. The Arduino Uno is an open source microcontroller to which you can connect sensors and code it to retrieve information from the said sensors. The fact it is open source is useful as no specific coding language in need to be used.

Looking for different sensors to connect the Uno, I came across 3 different options, an accelerometer, a gyroscope, and a Force Sensitive Resistor. The deciding factors were that the sensors had to be as thin as possible. In addition they had to be the cheapest possible sensor, without compensating quality and accuracy of the device.

I decided to use a Force Sensitive Resistor (FSR for short) because relative to the accelerometer and the gyroscope was the cheapest and the smallest. An FSR works as it is a malleable pad which has wires circling in it which change the resistance of the circuit as force is applied on it.

The FSRs would be placed between the head and the helmet, and would have the Arduino Uno attached to the outer shell with some LEDs to show when the force is too strong.

This is the final design that I used:
I was fortunate enough to have a teacher to provide the Arduino, and I bought the FSR for a reasonable price of £5.50 from a British company, although multiple FSR would be used in the final design. All the code that I used can be found in Annex 2.

Unfortunately, major problems arise with the electronic version. Firstly, the battery life isn’t very good, and would only last maximum a couple of hours, which for a device which in the case of skiing would only be used a couple times a year is not useful. In addition, even though the FSR is wafer thin and small, the Arduino Uno is quite cumbersome to have carrying around on the back of the helmet. However, the biggest problem with the electronic version is its price. Even though with a probable reduction in price with mass production, the total device (with multiple FSRs) would come between 50 and 100 euro (estimate). This is still too expensive for a device to be used for the mass market and to be found on every single helmet.

From this we can conclude that an electronic model would not be the optimal way of measuring the force on the head after a collision. From this, I decided to start investigating in possible mechanical models and conceptualizing them.
2. Mechanical Model

I considered many different concepts as ways of measuring force on a helmet, but I quickly realized that all that the device needs is a threshold that is surpassed in some way, rather than have a scale of different magnitude of force. This way a small simple mechanism can be created. Initially, I considered having a sort of putty, or dough, which for a given force would compressed and deform. I then realized that it wouldn’t work due to small repeated hits eventually creating the same deformation. I also considered having some liquid in a thin tube, which under pressure would circulate making a signal. Unfortunately this is difficult to calibrate accurately. I eventually thought that it would work best if a mass would move a given amount in a tube. At first I thought of having the mass break something in the tube, but then I discovered that I can use springs as a way of pulling the mass on either end, and when the mass is hit, it will slide along and clip in a ratchet preventing the springs from pulling the mass back.

Here is the original sketch:

![Original Sketch](image)

The mass at the centre has two springs in tension on either of its sides. When hit, due to its inertia, the mass won’t move, but the ratchet underneath it will. Then, once the mass has passed the ratchet, the spring will try to pull it back to the centre, without success, as the mass will be lodged in the ratchet. This system also leaves room for calibration, with the variables being the weight of the mass, the distance it moves, and the stiffness of the springs.
2.1 First prototype (PT01)

For my first prototype, I wanted to create an enlarged version of my device for a proof of concept. I split the production into phases: the centre module (or mass) and the frame. Instead of using springs, I decided that it would be better to use elastic bands, as they are cheaper, weigh less, can store more energy than springs, and can be replaced readily. The job of the frame is to have something for the centre module to slide on, somewhere to attach the elastic bands, and somewhere to put the grooves for the ratchet.

The frame and the centre module were made from aluminum tubes and bars so that it can be easily cut with a saw and so that the whole device can remain relatively light. Also I had to find a thin flexible piece of metal that would be used to clip the centre module into the groove of the ratchet.

This is the production process and final design:

The mechanism in itself is very simple, the centre module, with a defined mass of 63 grams with addition washers giving it 200 grams, is locked in the middle by the rubber bands under tension. When hit, the centre module will click into the ratchet. The top of the centre module can be coloured green in the centre, and red on either side, so that when it moves and clicks the person with the helmet can know if the collision surpassed the g-force threshold.
The difficulty of this first model is a system to which the centre module moves a defined amount with 50g. The main variable that I decided to use is the type and amount of rubber band. The elasticity depends on the thickness of the bands, and the number of bands that are used.

Therefore I decided to test as many different types of elastic bands as I could find, and doing an extension test. I did this to see how much they stretched when a certain weight is applied. In total I tested the extension of 11 elastic bands, each ranging in length.

2.1 PT01 (Extension Results)

Along with the elastic bands for PT01 I also decided to test hypothetical rubber bands for PT02, assuming the mass of its centre module. In each scenario I tested a normal rubber band, a thin band and an extra thin band; I also tested a band cut into a string (rather than a loop) to see its implications on the extensions. The extension of the rubber band according to the weight added was measured and plotted.
Even though these results seem valid, after I did some research on the elasticity of a rubber band and how it works, I ran into a major problem. To explain this problem I must first explain how rubber bands work.

Rubber is a natural polymer, and the chains of molecules in rubber are naturally elastic: when a force is applied they are stretched, and when that force is removed, the elastic polymers in rubber spring go back to their original length. As one knows from experience, initially it is quite easy to stretch an elastic band, but the more you stretch, the more difficult it becomes. This can be easily explained: when un-stretched, the chain molecules in the band are all tangled up. Applied force is equivalent to straightening or untangling these molecules. If too much force is applied, the links between the chains breaks, snapping the elastic band.

Another important observation that we notice when we stretch elastic bands is that they warm up. This thermodynamic aspect of rubber bands is very interesting. As we know, when a rubber band is stretched, its molecules are straightened. This means a decrease in volume. This causes its temperature to increases (just like a gas, which heats up when compressed). This thermodynamic identity for a rubber band can be expressed with the formula:

\[ dU = TdS + \tau dL, \]

Where \( T \) is the temperature, \( \tau \) is the tension, \( U \) is the internal energy of the rubber band, \( S \) is the entropy, and \( L \) is the length. Therefore we can indeed conclude that a rubber band does heat up when stretched.

Another important observation that has to be made is whether elastic bands always follow Hooke’s Law. Hooke’s law states that elastic objects such as springs extend in proportion to the force that acts on them. If Hooke’s law can be applied to rubber bands, then the extended distance is directly proportional to the force exerted and thus has a linear relationship. However, if we observe the results of the extensions of elastic bands illustrated above, we notice that the relationship is more parabolic than linear. This is the general consensus: Elastic bands are only loosely Hookeian. In addition, like springs, rubber bands have an elastic limit.

Finally, the literature revealed that the ambient temperature greatly alters the elasticity of the rubber band. This is problematic for a force measuring device as in the case of cycling or skiing, the temperature can vary greatly.

In conclusion, the force measuring device cannot use elastic bands, as they do not follow Hooke’s Law and their elasticity greatly depends on the weather. This leads to serious revision for the possibilities for the next prototype - evidently is seems best to use steel springs.

All the links that I used to explain how rubber bands work and the effect of temperature on the elasticity of rubber bands can be found in Annex 3, where there are links to detailed analysis on the thermodynamics of rubber bands.
2.2 Second prototype (PT02)

For the second prototype I decided to miniaturize the model of PT01 into something that could be found on the back of someone’s helmet. I reduced the mass of the centre module to just 30 grams, and I replaced the ratchet system with a single hole where the centre module would get stuck. In addition I replaced the idea of using extension springs with compression springs. Instead of the centre module stretching the spring, the springs acts as an obstacle for the centre module to move; this way the springs don’t lose tension over time (the mathematics and physics for compression springs is exactly the same as that of extension springs).

Blueprints of PT02 can be found in Annex 4, where there is a visual explanation from every angle, with all the lengths measured. Here is an example of the side view blueprint without the lid, drawn to scale.
PT02 is very similar to PT01 except there is no ratchet system. When there is no force, the centre module rests on a flexible thin piece metal bent into an arc. On top of the module in the centre there is a green icon with red ones on either of its sides. When the device is hit, due to its inertia, the centre module will sway to either the right or the left. To set the device off, the module has to move a centimeter, before the flexible metal gets caught in the hole (in the middle of the device) changing the icon on top from green to red.

### 2.2 PT02 (Explaining springs)

To understand what sort of spring I should be using- relation between the elasticity constant, and the length of the spring- I had to understand the mechanics of springs.

![Diagram of a spring](image)

A spring is simply a bar that is being twisted. The shear stress on the spring is equivalent to Hooke’s Law.

\[
\tau = G\Psi
\]

(1)

Where \(\tau\) is the shear stress, \(G\) is the modulus of rigidity of the metal (varies from metal to metal) and \(\Psi\) is the angle at which the bar is twisted.

As we know from geometry:

\[
\Psi L = \theta r = \delta
\]

(As the angle is so small the relationship is basically linear)

Rearranging:

\[
\Psi = \theta r / L
\]

(2)
If we substitute (1) into (2), then we get the following formula:

\[ T(L, f) = G\theta f/L \]

(At any radius \( f \) from centre of the bar)

In other words, the shear stress within a bar of length, \( L \), and at a subring of within the bar at radius \( f \) is equal to the modulus of rigidity, multiplied by the angle of rotation and the radius, all divided by the length of the bar.

The total torque (twisting force) = the sum of shear stress in each ring (stress times the area it acts over) multiplied by the distance from the centre, \( f \). The area of each subring of thickness \( df \) at radius \( f \) is \( 2\pi f df \). Therefore, the total torque in the bar is given by the following integral:

\[ T = \int_0^f \left( G\theta f^2 \right) df = \frac{\pi G\theta r^4}{2L} \]  

(Number crunching) \ldots \ldots \quad (Total Torque)

Rearranging, we get:

\[ \theta = \frac{2TL}{\pi G\theta r^4} \]

Now we know that total torque \( (T) \) = force applied on spring \( (P) \) multiplied by the radius of the spring \( (R) \). Note that \( r \) above is the radius of bar under torsion – or the wire used for the spring
\[ \theta = \frac{2 * P R * L}{\pi G r^4} \]  

(3)

To convert torque in the bar into that of a spring we use the following formula:

\[ L = 2\pi R n \]  

(4)

Where \( L \) is the length, \( R \) is the outer radius, and \( n \) is the number of coils (each coil being made of a length of wire equal to \( 2\pi R \)).

We know that the total energy in the spring is the same as the energy in the twisted bar/wire due to torque. This is given by the area under the graph relating extension (or twist) to force (or torsion).

\[ e \text{ (similarly } \theta \text{)} \]

The area under the line is given by \( Pe/2 \) or \( T \theta/2 \). Therefore,

\[ Pe/2 = T \theta/2 \]

Or \( Pe = T \theta = PR \theta \)

Or \( E = R \theta \)  

(5)

If we substitute into (4) and (5) into (3).

.... (Number crunching)

\[ e = \frac{4PR^3n}{Gr^4} \]

\[ P/e = \frac{Gr^4}{4R^3n} \]

Since the diameter of the wire is 2 times the radius \( (d=2r) \) and we define \( C = R/r \) (radius of spring, over the radius of the wire):

Then;

\[ P/e = k = \frac{Gd}{8C^3n} \]

Where \( k \) is the elasticity constant of the spring.
In short, the elastic constant of the spring is equal to the modulus of rigidity of the material used times the diameter of the wire divided by 8 times the ratio between the radius of the spring and the radius of the wire cubed, and divided by the number of coils to the spring.

With this equation we can calculate what dimension of springs we need for the impact measuring device.

Given that the frame of the device is 10mm wide, we need a spring which is about 7mm diameter. A design weight of 33g was used for the inertial mass. Finally, the number of coils to the spring was set at 12 for thin wire (less than 1 mm) but adjusted downwards so that the spring would be 1cm long when fully compressed (so the spring would fit in the same space longitudinally).

Using the above formula, to plot different thicknesses of wire against the g-force required we get the following graph:

This graph is very useful because it means one can custom the reactivity of the device by changing the thickness of the wire in the spring. This may be due to additional research identifying new thresholds. Also for a high performance downhill ski helmet we might want a trigger level of 100g, while a helmet of lighter construction for a commuting cyclist might require only 30g. Likewise, a child may have a lower force threshold than an adult. Ultimately this is what makes the device work-being able to create a threshold for the g-force based on the thickness of the wire.
All the data that I used for the mathematical calculations and aid from internet research can be found in Annex 5.

2.2 PT01/PT02 (Testing)

For my PT02 I decided to use a spring of 12 coils of 8mm wire. This would move the inertia weight (of 33 g) by 1 cm when subjected to a force of about 25g. This is less than the 50g mentioned before as a risk threshold. However, this can be easily adapted in the future to any desired level and it allows less destructive testing of the prototype.

To test that my PT01 and PT02 devices work, I decided to build a rig (…as my sister wouldn’t agree to cycle into a car with them strapped on her head…). The rig is based on one that I saw in Imperial College London which was an example of a helmet testing rig.

The rig proved to be successful for PT01, where I had it attached with jump cords to the frame to imitate the recoil of the head during a collision. The device was hit by a hammer on a pendulum from a defined height.

For PT02, to resemble a more lifelike test, I added a test dummy (called Edith) to which I could attach the device. The dummy proved to be successful. A difficulty with making the testing rig was to create a device which could easily be erected and dismantled. In the end I used wooden elements, all bolted together.
**Business Proposition**

A device such as PT02 might be a good commercial proposition. Doing some calculations on ordering mass quantities of springs, I calculated the cost of production can be brought down to perhaps 3.00 euro (estimation). While two PT02 would be needed per helmet to take into account the different direction in which blows might happen (i.e. two devices set perpendicularly to each other), this is a reasonable supplement when compared to the cost of production of a helmet.

My idea is that the “Impact measuring device” should be found on every helmet and so I want it to be a product for the mass market. **Force measuring devices do already exist**, although they are made specifically for professional American football players, they cost **more than $300** and as they are electronic (using accelerometers), their **battery life is maximum 1 hour**. This is not what I want to create- I want a device to improve the safety for everyone, all the time.

As of now, there is no reset button on PT02. This means that once the threshold has been surpassed during a collision the red warning remains permanently in place indicating that the helmet is no longer valid. In addition, this would encourage people to buy helmets more frequently, thus making the business more profitable. Of course, the majority of people that would have the force measuring device would never see it turn red, as it takes a substantial blow to set it off.

**PT02 is as small as the ‘Impact measuring device’ can get.** The centre module has to be a certain size to show the switch from the green icon to red icon (minimum 4cm). Also a certain length is needed for the weight to have sufficient mass while remaining sufficiently thin.

Furthermore, after testing multiple springs, we found that 8mm spring diameter is optimal, because if any smaller, then the ratio between the diameter of the spring to the diameter of the wire would be too high, thus making the spring buckle.

I did thorough research on different types of springs by making some myself (winding a thin metal wire under tension around a bolt), and buying a wide range of widths and testing them.

**All the springs tested:**

![Image of springs](https://via.placeholder.com/150)

The length of the spring is determined by factors at each end. At the end supporting the weight, there is the 1cm required movement plus a margin to allow the weight to pass fully the required
blocking position. At the other end, there is the maximum compressed length of the spring (its fully compressed length of 1 cm) plus a margin. This gives a total spring length of some 3cm.

Therefore the total length of the device is 10cm (two springs plus the weight). To make a more “svelte” and discrete version, for a third prototype (PT03), one could look at slightly curving the device. Curving the springs won’t make any significant difference to the mechanics of the device, but might create more friction. I am currently looking into the possibility of 3D printing a curved PT03. This would be a further refinement.

A picture of PT02 opened up on a A4 sheet of paper with 5mm squares (the device is 110 mm).

**Conclusion**

In conclusion, I was able to create a device which could be realistically put into mass production. I found that that head injuries are a growing problem, and that their aftermath can spread damage across large areas of the brain as a damaging chain reaction is set off in brain receptors. I also showed that helmets lose their validity once a strong collision has occurred, due the deformation of the lining inside the helmet.

I proved that even though it was possible to recreate, an electronic model would not be feasible except for high performance professional helmets. Its price, size and battery life were key to its lack of success.

I then decided to create mechanical version using rubber bands which proved unsatisfactory, as the elasticity of rubber bands greatly varies with heat.

Refining the first mechanical version and especially miniaturizing it proved difficult. Understanding the mechanics of springs to create the smallest one possible was a task, but I managed to produce a device which could be customized depending on the preferred strength of the owner (preferred g-force).

Prototype 2 is ready for some real collisions. Hopefully with a similar device, doctors can know on the spot the gravity of the incident, and prepare treatment immediately without losing time at the hospital.

And helmet manufacturers should be interested in marketing this device. It meets consumers’ desires to understand how bad a blow might have been, thus giving a particular marketing message around safety (the reason for buying a helmet in the first place). It is also more likely for customers to replace helmets that have suffered a significant blow thus increasing sales.
Acknowledgements

I would like thank Mr. Cafferkey for his aid and the possibility of using his Arduino Uno for the project. In addition I would like to thank my sister for her helmet, and Edith for dedicating her head to science. A major thanks to my father for using his garage tools to make all the devices and the rig, and helping me understand the complicated mechanics of springs.

I have dedicated a lot of time on this project, over 6 months, and it would not have been possible without all the motivation and support from the people around me.
Annex 1
Sites and article used for information on Injuries:

http://neuropathology-web.org/chapter4/chapter4aSubdural epidural.html

http://www.timeshighereducation.co.uk/comment/opinion/science-writing-award-new-hope-for-traumatic-brain-injuries/2007652.article


http://www.npl.co.uk/upload/pdf/forceguide.pdf

Mazdak Ghajari's work:


http://dx.doi.org/10.1080/13588265.2011.616078

http://dx.doi.org/10.1080/13588265.2011.559798

http://dx.doi.org/10.1016/j.aap.2012.04.016
Annex 2
Code used for programming the Arduino Uno. Written in programming language C.

```c
int fsrAnalogPin = 2;
int LEDpin = 9;
int fsrReading;
int LEDbrightness;

void setup(void) {
  Serial.begin(9600);
  pinMode(LEDpin, OUTPUT);
}

void loop(void) {
  fsrReading = analogRead(fsrAnalogPin);
  Serial.print("Analog reading = ");
  Serial.println(fsrReading);

  LEDbrightness = map(fsrReading, 0, 1023, 0, 255);
  analogWrite(LEDpin, LEDbrightness);
}
```
Annex 3
Explaining rubber bands:

http://depts.washington.edu/chem/facilserv/lecturedemo/EntropyofRubber-UWDept.ofChemistry.html
http://tuhsphysics.ttsd.k12.or.us/Research/IB10/RajeJaneHerm/index.htm
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=5155670
http://www.schoolphysics.co.uk/age14-16/Matter/text/Rubber_band/index.html
Annex 4
Explaining springs:

http://www.thecartech.com/subjects/design/Automobile_suspension.htm
http://www.roymech.co.uk/Useful_Tables/Springs/Springs_helical.html

Prices and analysis of spring prices:

http://www.thespringstore.com/catalogsearch/result/?q=compression+spring&cat=13
http://www.planetsprings.com
http://www.entexstocksprings.co.uk