

Promoting & Assisting Concussion Diagnosis in Boxing

10 page Summary



Problem and Opportunity

Concussion

A concussion is a traumatic brain injury caused by a violent blow to, rapid deceleration or an accumulation impacts to the head where the brain has been caused to crash against the sides of the skull. Concussion often leaves no visible external damage but internally the brain is at risk of detrimental neurocognitive effects. These can manifest immediately or over the subsequent days, months, weeks and even years down the line.

Symptoms

Short term days to weeks afterwards



Painful headaches, dizziness, disorientation, nausea, poor motor skills and even vomiting



Trouble sleeping, sleep disturbances and imbalanced sensitivity to light.



General cognition difficulties such as memory loss or retention, decreased mental capacity and ability to understand with complex information.



Irregular, sometimes irrational behaviour. Often this manifests in increased irritability, anxiety or depression.

Long term danger of life long damage



Overall standard of life and happiness is reduced from the above short term symptoms becoming permanent



It is becoming increasingly evidenced that multiple incidences of concussion can lead to Chronic traumatic encephalopathy (CTE). A neurodegenerative, sometimes fatal disease associated with the development of dementia

Boxing

Contact sports such as American Football and rugby have concussion monitoring systems being introduced and tested products to assess concussion and dangerous impacts but no such system has been rolled out in boxing. Despite being a sport where the point system rewards blows to the head and instant victory is granted if the an athlete successfully knocks out their opponent; concussion isn't talked about enough in boxing and there is inadequate procedure in place to protect against it.

90%

Of long term boxers will suffer a concussion at some point in their careers

88%

Of concussions are likely to go undetected and undiagnosed

Opportunity

No technology that exists detect concussion; the only way it can be diagnosed is by a medical clinician. However, there are actions that can be taken to protect and prevent against it. For many boxers there is no one or no thing in place that can give any indication of what kind of situation might have put them at risk of concussion. Going for a medical assessment is often completely self directed with little to no guidance provided by gyms to advise when it might be necessary. Similarly there is no way of tracking the amount of damage a boxers brain might be undergoing over time. Current impact assessment tools are either expensive systems only available for research or are else specialised to other sports and not suitable for use in boxing.

The Brief.

“Design a solution that can monitor a boxers risk of concussion. Aiding in the process of concussion treatment via earlier and more regular impact analysis”

Research

Stakeholders



Boxers

Primary users. The product aims to protect amateur boxing athletes from suffering dangerous consequences of concussion.



Gym Owners

Target Market. Research indicated the product would be more likely to be used if it was provided by and encouraged by the boxing gym.



Medical Professionals

The treatment. A concussion must be diagnosed and cared for by a trained clinician. The product will act as an assistive service to them

User Engagement

Being a member of the University of Glasgow boxing and Thai boxing societies as well as having trained at Glasgow's largest boxing gym, Kynoch boxing, I was in a fortunate position of having multiple connections within boxing. Additionally, I made contact with several medical professionals who had expertise in the treatment of concussion either both within the sport of boxing and rugby. Thus, I was able to establish regular communication to gain useful and informing feedback with each category of stake holder on my design choices and iterations as all agreed to continue to help me throughout the project after initial contact although some were more frequent responders than others.

Boxers were interviewed on their experiences with concussion and there was a wide range of attitudes towards the issue. A common theme was that concussion generally wasn't as well understood as it should be in such a high risk sport, particularly knowledge of when to look out for a concussion was lacking. Notably, some boxers were of the attitude that concussion was not as big an issue as it is made out to be and could be pushed through. Boxer's decisions for what to do if they suspected a concussion was found to be heavily influenced by advice from their coach/trainer which again, is often not in-line with standard medical protocol. There was also evidence to suggest that some boxers would conceal concussive symptoms from clinicians as they did not want to get temporarily banned from participating. It also quickly became apparent that sparring is where key protective action should be taken as boxing fights were commonly far apart. Boxers took part in sparring frequently and I identified that this was where potential damage to the brain could build up and cause serious effect. Thus these insights directed the solution to be marketed towards boxing gym owners (often coaches at the said gym) and would aim to improve their knowledge of when their athlete might be in danger, giving them alerts as to when they should be taking preventative measures or recommending that their athlete undergo medical assessment. The suggestion is that the product be implemented as standard practice in a gym's sparring policy.

"I woke up in the hospital - last thing I remember was warming up"

"I see fighter's leave their career in the gym"

"There's no time to draw breath and assess the damaged caused"

"Boxer's don't know how much they're being hit in the head"



Desk Work

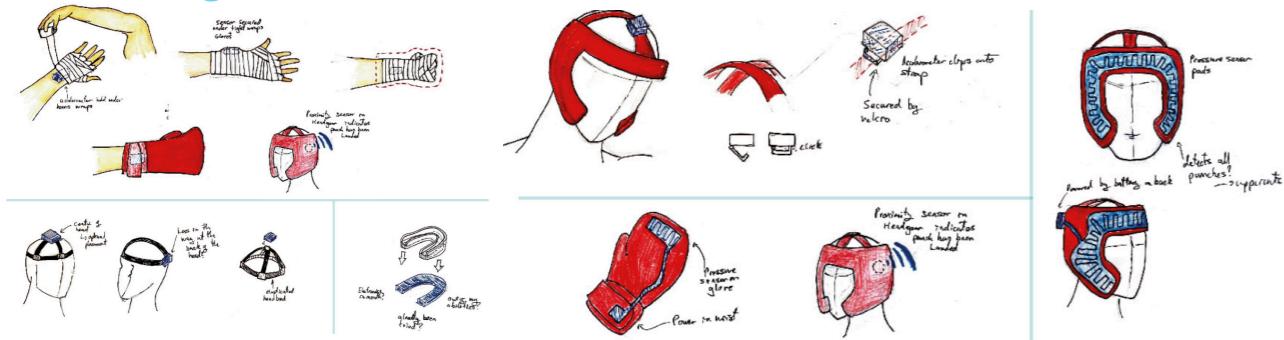
Reading studies published in blue ribbon journals was beneficial as it allowed me to better understand the intricacy of the problem in general as well as specifically in boxing. These not only highlighted the severity of the problem, some even suggested the need for the potential for a product to be introduced as a preventative system to improve current practices. Evidence suggested that both number of punches per round as well as number of power punches per round (i.e. accumulation of punches and high accelerations induced on the head) were key indicators for causing harm to a boxer's brain so this was the basis for how the my solution would assist in informing users when the fighter was in danger.

Key Product Requirements

- Will detect punches and log punch count
- Will measure the magnitude of a punch impact and alert to dangerous values.
- Cannot impede performance or distract the wearer during sparring, being as discrete as possible when in use.
- Time spent learning how to use, setting up or carrying out maintenance is to be kept to a minimum.
- Price must be affordable for a boxing gym to be able to comfortably afford multiple.
- Cannot put the boxer in any unnecessary danger or exacerbate an existing situation.
- Will provide data that has the potential to be useful for a medical professional carrying out diagnosis and treatment of a concussion.

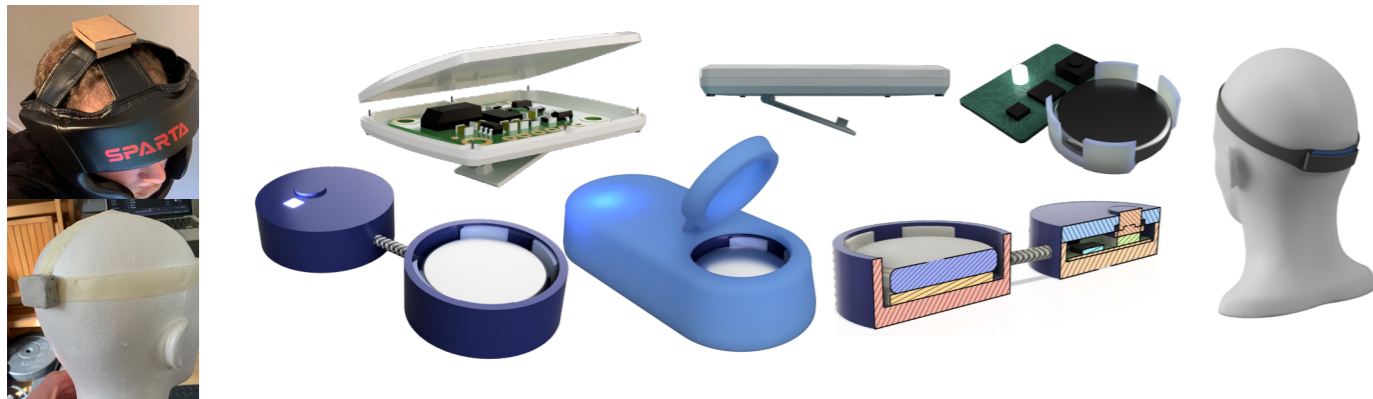
Enclosure and Protective Sleeve

Starting Point



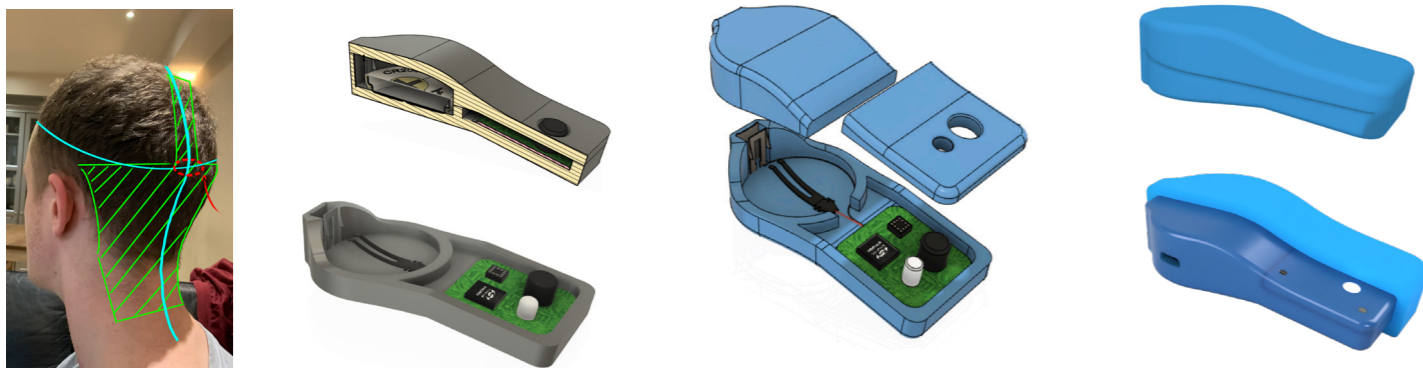
The project initiated with exploration into how various different motion and proximity sensors might be able to detect punches when integrated into boxing equipment. After consultation with experts from University of Glasgow, using an accelerometer and associated system was chosen

Development



As new iterations of the design were made, these were modelled using rough prototyping. This was extremely helpful for both my own visualisation and for displaying to my user groups to obtain feedback on the design. Safety considerations established the need for an impact absorbent, flexible enclosure to protect the users head encase of damage if an impact were to connect with the rigid electronics enclosure which could make the impact worse.

Arrival at Final Design



The location of the sensor was chosen specifically so that it was in the **safest** area possible to avoid incoming impacts whilst also located centrally on the skull for **optimal accuracy in data capture**. The enclosure for the electronics is designed to be **ultra slim** and use the least amount of material possible. The components were angled specifically to conform to the curvature of the human skull and the enclosure was built around them. The protective sleeve was also designed with the same design principals and to fit snugly around the enclosure.

Full Scale Prototyping



A full scale prototype of the product was 3D-printed in PLA for the rigid electronics enclosure and flexible TPU for the protective sleeve. With this I was able to evaluate the sizing of the product as well as test and gain feedback on user interactions.

The main focus of the user testing was to see if the product would fit comfortably, would not restrict the users performance in anyway and would be fitting would be a quick and hassle free process as per user requirement. The device was fitted on several people, with no users expressing reports of significant discomfort or concern over performance with comments being the process was easy, stress free and quick. The presence of the headband was more noticeable than the feeling of the having a device on the back of the head. Users were more aware of the device when wearing boxing headgear but it could still be fitted tightly and securely.

The print was also useful for testing if the press-fit mechanism in the removable part of enclosure would connect securely to the base of the enclosure and if it could then could still be opened appropriately.

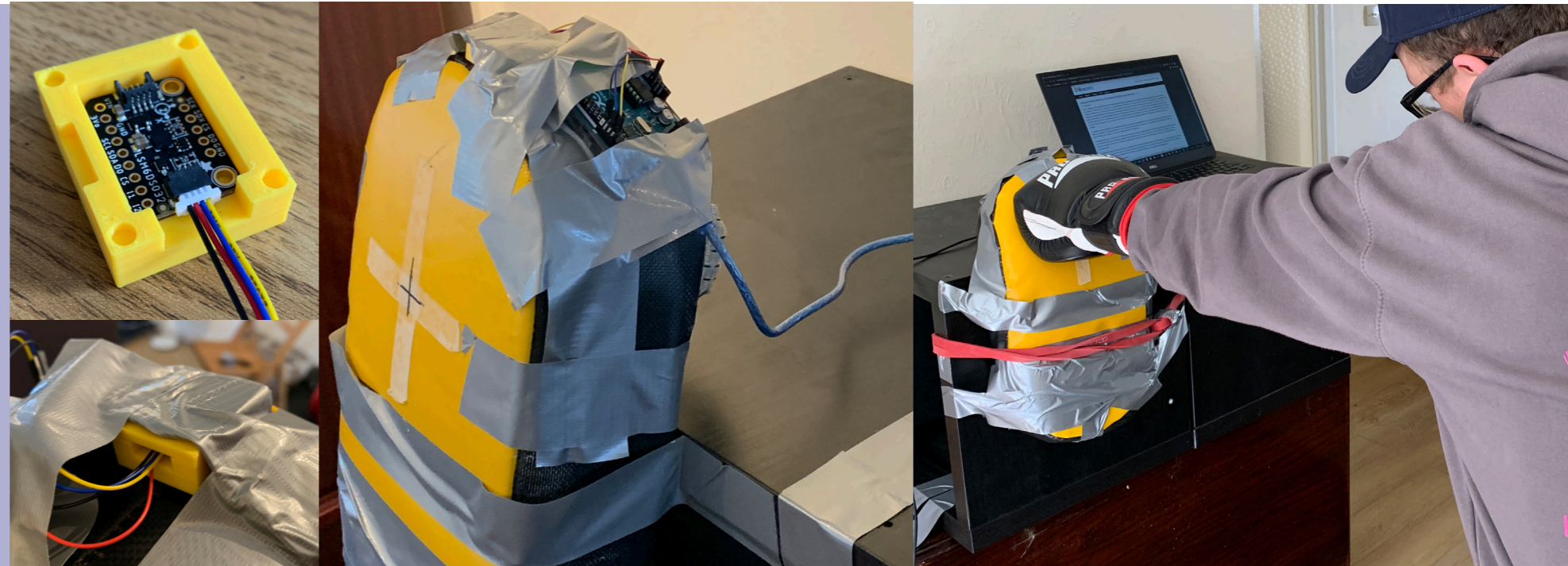
Gathering & Analysing Punch Impact Data

Data Collection

A breakout board for the triaxial high-performance accelerometer, the H3LIS331, was wired to an Arduino uno R3 and was programmed to collect acceleration values, measured in g in the x, y and z axis, every millisecond. Fitted securely into an custom 3D printed enclosure, it was rigged in a construction designed to emulate that of the human head on the pivot point of the neck.

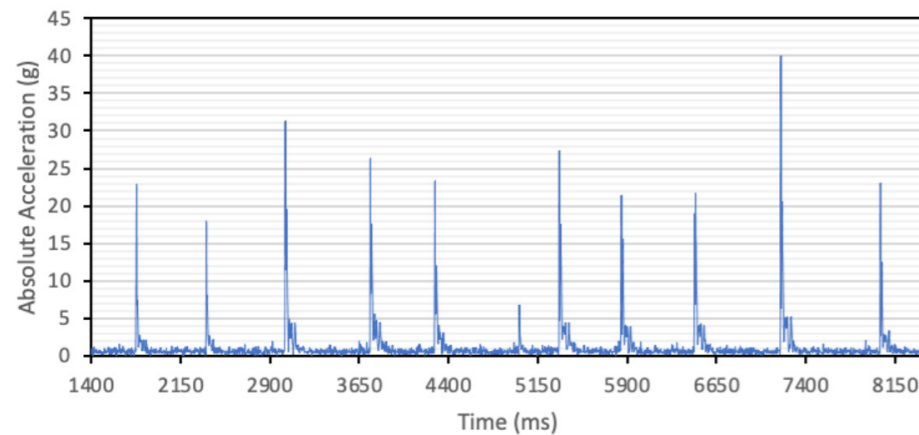
After the experiment was calibrated to ensure reliable, repeatable data was being output, a series of different punches were delivered to establish a varied and comprehensive data set.

Recorded accelerations were of greater magnitude than originally expected due to the construction not managing to adequately recreate the resistance to punches provided by the human neck. However, I was still able to gather usable data for my original intention which was detect when a punch had been delivered, to measure the magnitude of a punch and to establish a warning system for dangerous head accelerations

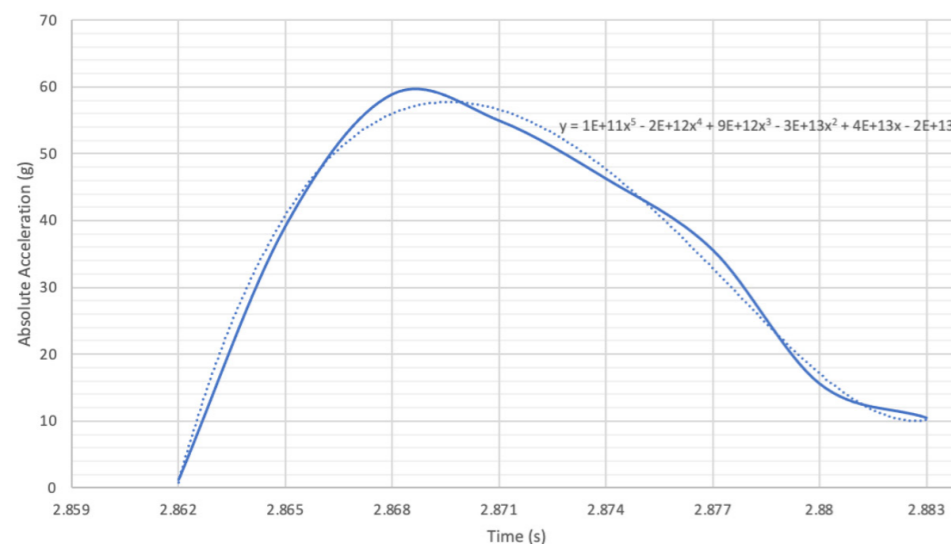


Data Processing

Light Jabs and Straights



Jab #3: Absolute Acceleration Vs. Time



The three acceleration values were combined to give absolute acceleration values. A punch detection was established by comparing the acceleration values of the lightest expected punches and those caused by a boxer defensively "bobbing and weaving" out of the way of punches. The punching data was consistently greater than head movement values so a threshold could be established.

The 'Head Injury Criterion' (HIC) is metric that provides a quantitative estimation of head injury risk based on the acceleration-time pulse waveform of a person's head. I was able to isolate an individual punch and identify the start and end times values. I derived a unique formula for finding HIC which was a combination of an adapted version of the trapezoidal rule with the original HIC equation as well as an additional alteration to adapt my data into realistic values. It would be this formula that would be programmed into the products MCU to give alerts to the user of dangerous impacts.

$$a(t)_{abs} = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

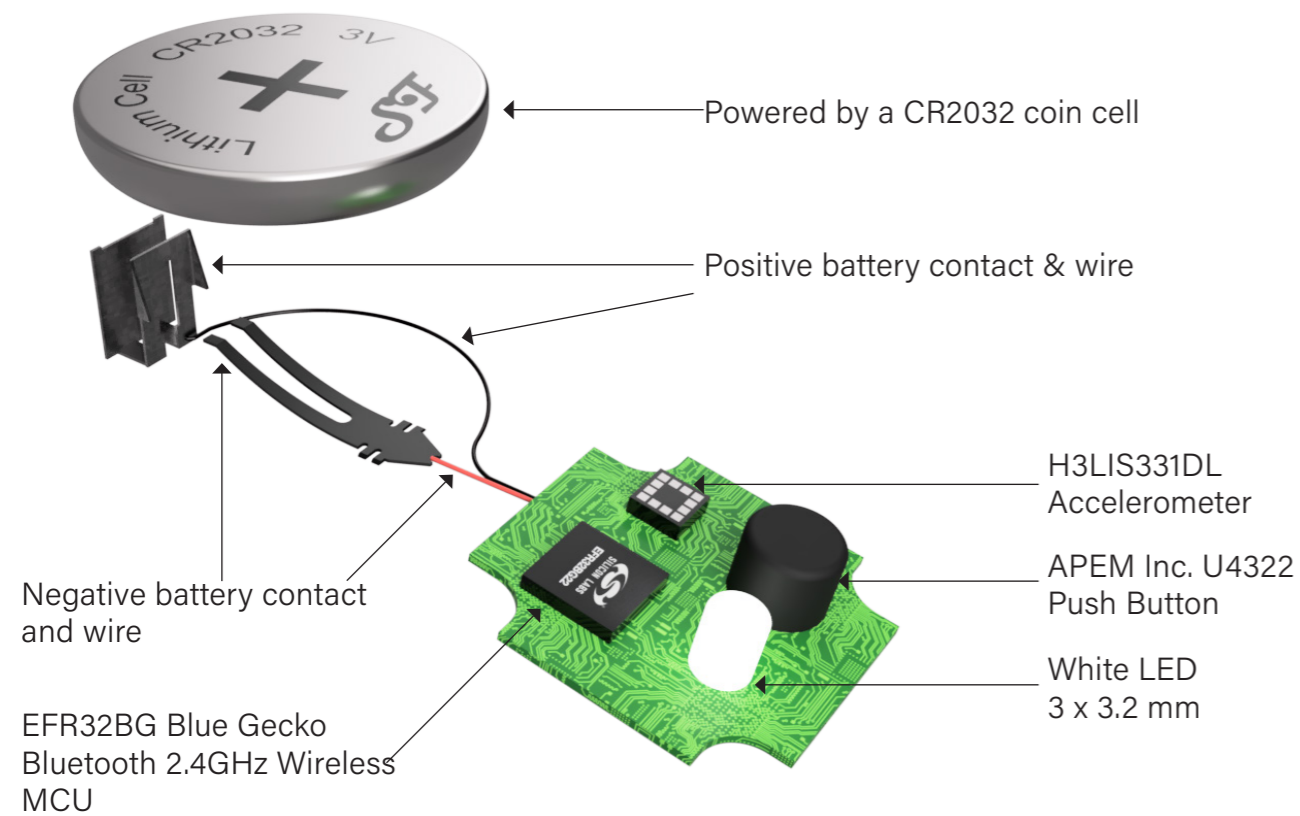
$$Area_{total} = \sum_{i=1}^n \frac{(a_n + a_{n+1})}{2(t_{n+1} - t_n)}$$

$$HIC = \frac{1}{3.643} \left[\frac{Area_{total}}{t_2 - t_1} \right]^{2.5} (t_2 - t_1)$$

Key Data Values.

- **16g and above values register as a punch.**
- **Warning 1:** An HIC value of 400+ relates to ~25% risk of concussion and the athletes movements, decisions and actions should be monitored closely (for signs of unusual behaviour)
- **Warning 2:** An HIC value of 600+ relates to ~50% risk of concussion and it is recommended that the athlete should stop sparring and get concussive assessment from a medical professional.
- **Warning 3:** An HIC value of 800+ relates to ~75% risk of concussion and it is highly recommended that the athlete should stop sparring and immediately go for concussive examination from a medical professional.

Electronics



As the component choices would dictate the size and price of the product, two key issues for users, strong consideration was taken for the optimal system of components. The accelerometer was chosen first as it provides the main functionality of the P.A.C.T system. The H3LIS331DL not only met my requirements for appropriate punch analysis but also had a breakout board version which meant I could conveniently use it in my experimental testing.

The MCU was chosen for as it could interface with the H3LIS331DL, its bluetooth output at 1kHz and its ability to handle motion data with its ARM cortex M4 processor. Given that simplicity and convenience were paramount to the user interaction of the product, the only necessary additional bulky components were an LED and push button for the user to turn the device on and off. A coin cell was desired for the battery due to the slim profile and a CR2032 was chosen specifically due to its affordability, widespread availability allowing the user to conveniently replace it and its battery capacity allowing for a long duration of use.

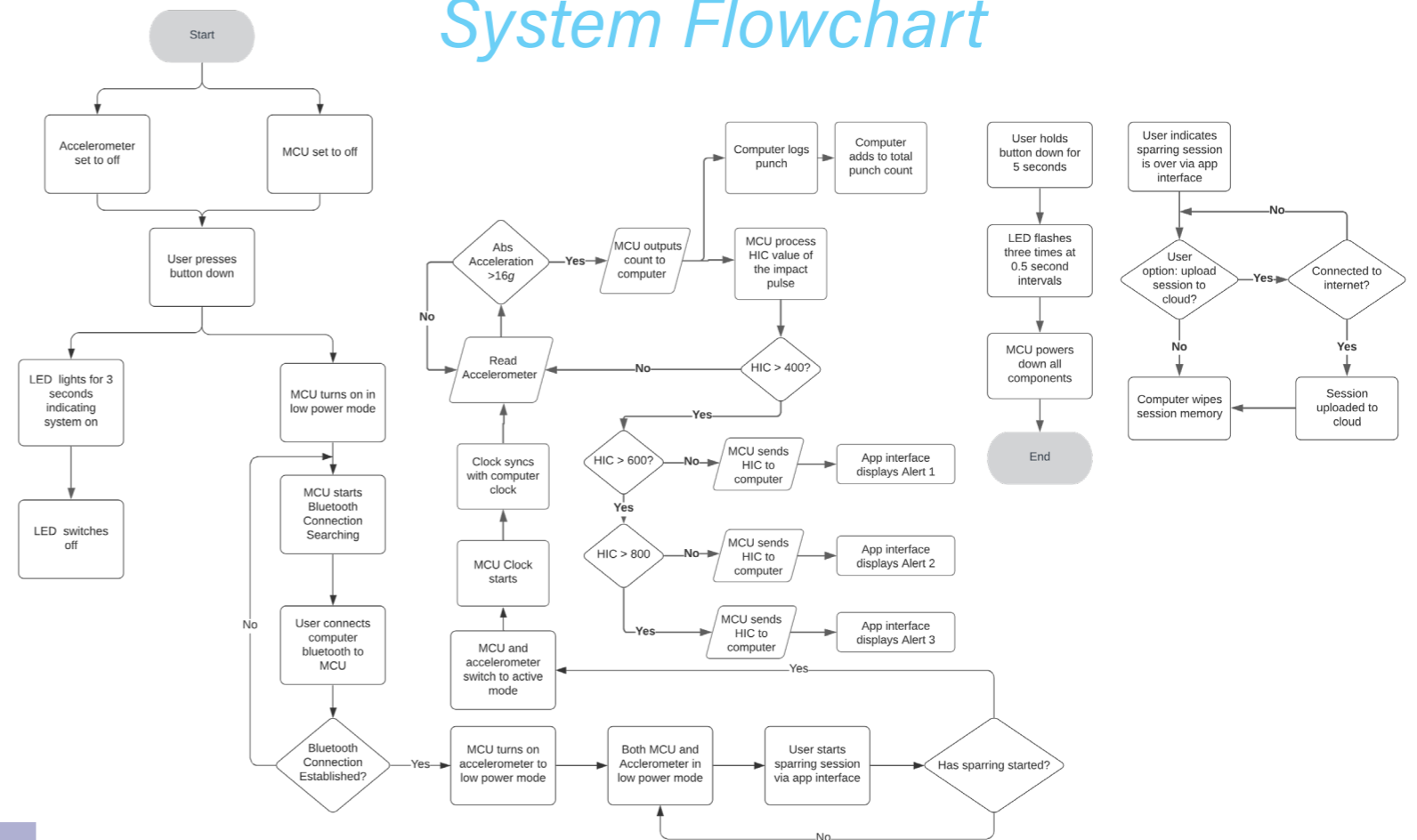
Battery usage was estimated by working out the total load current load per hour from the estimated time the device would be used and the current draw for both low power and active modes of the primary components. Given by:

$$\text{Approx. Battery Usage} = \text{Battery Capacity} / \text{Load Current} = 225 / 0.3943 = 570.631 \text{ Hrs}$$

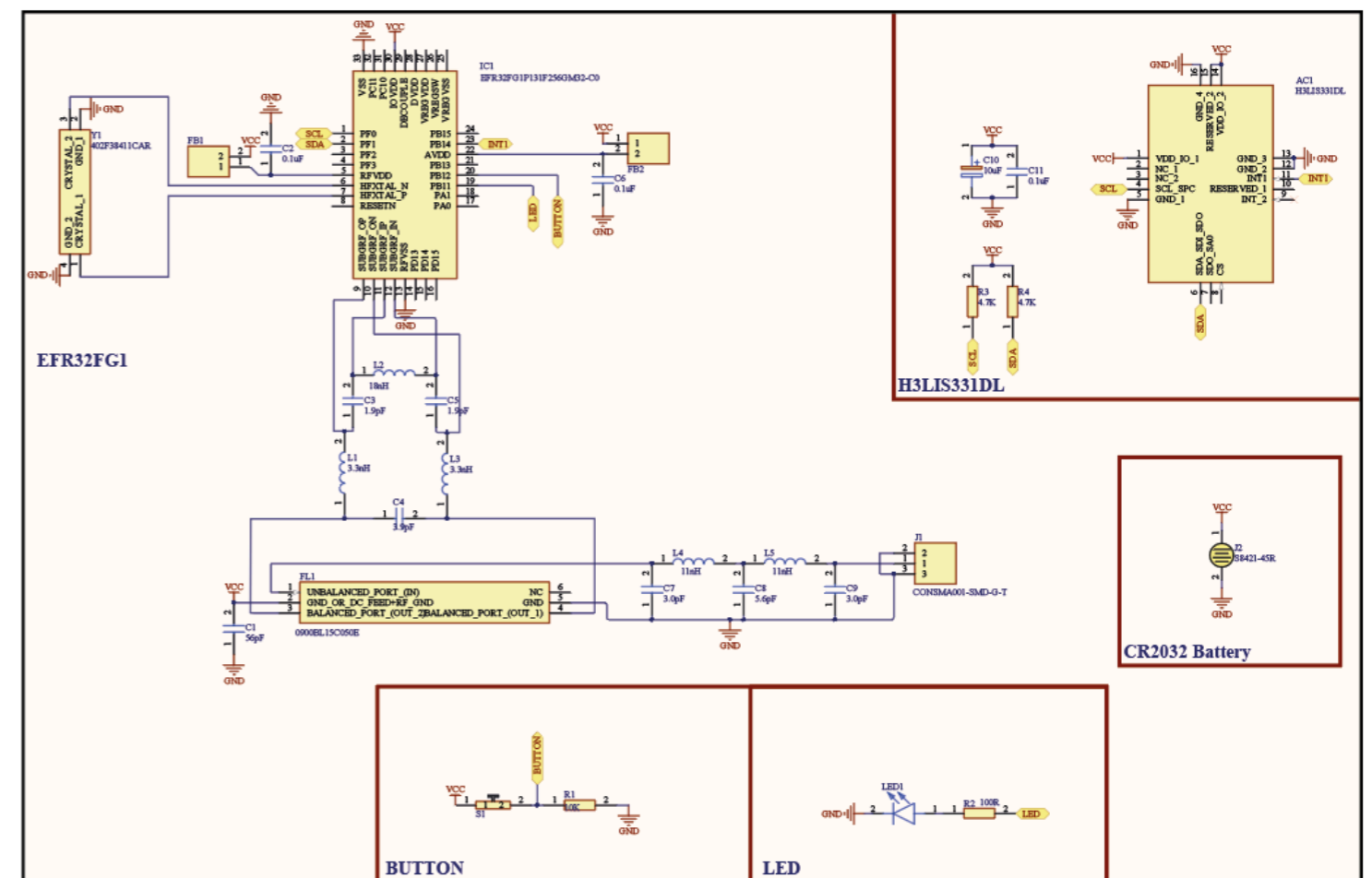
If device is turned on 5 hours per week (estimated time sparring time) this would equate to a predicted lifetime of 114 weeks. Even if a slight over estimation, the product would still not require frequent battery change which is desired for the user requirement of the product being low maintenance.

Finally, the other necessary components for full functionality in the circuit were established. This was done by working collaboratively with an electrical engineering graduate and allowed for the full circuit schematic to be created, ready to take to a PCB manufacturer for production.

System Flowchart



Circuit Schematic



Product Overview

The P.A.C.T system is designed to assist in protecting boxers from concussion. During sparring, athletes wear a sensor fitted into a sports headband. Real time alerts of potentially dangerous punches are provided to an observer (coach, medic or otherwise) via bluetooth connection to the P.A.C.T app on a smart device.

In the short term, early intervention can be taken to stop a boxer who may have sustained a concussion sustaining even more unnecessary harm. They can then be further advised to get a concussion assessment from a doctor. The promotion of more regular assessment, means that less undetected concussions occur allowing for better treatment and prevention of further damage to the brain.

In the long term, data from each sparring session can be stored creating a historic record of the athlete's brain health. This can be used to judge whether a recovery period should be suggested as well as an additional benefit of being able to identify how the boxer can improve defensively.

The P.A.C.T system can integrate mobile footage of a sparring session with the punch data so that medical professionals are given an more complete picture of the mechanism of injury, subsequently assisting in their assessment of severity and treatment recommendations.

For the Athlete

- No athlete wants to live with the potentially devastating effects of associated with poor concussion management in their active career. Hence, prevention and monitoring is in the interests of their short term ability to perform and long term brain health.

For the Gym Owner

- Can use punch analytics to plan and structure training to keep their athletes healthy and active.
- By introducing a protective measure into their gym environment, it proves their intention of care for the athlete instilling trust from boxers, their families and potentially in legal cases regarding a brain injury in their gym
- The affordable price also means the gym owner does not have to break the bank to do so.

For the Medic

- Medical Professionals are given useful information to help them better understand the situation associated with the injury that caused an athlete a concussion. With better understanding comes more informed analysis and decision making then subsequently potentially better treatment.



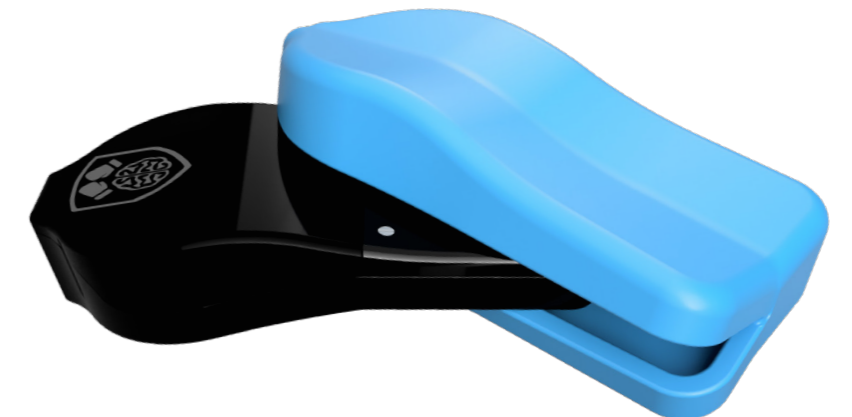
Simple, convenient design. Turn it on, connect to your device, slot into headband and your ready to start sparring.



10.5mm

48.6mm

Ultra slim design makes the sensor barely noticeable when sparring either worn alone or with headgear



Flexible Polyurethane rubber casing protects the device and the athlete if an impact connects with the sensor

Product System and User Journey



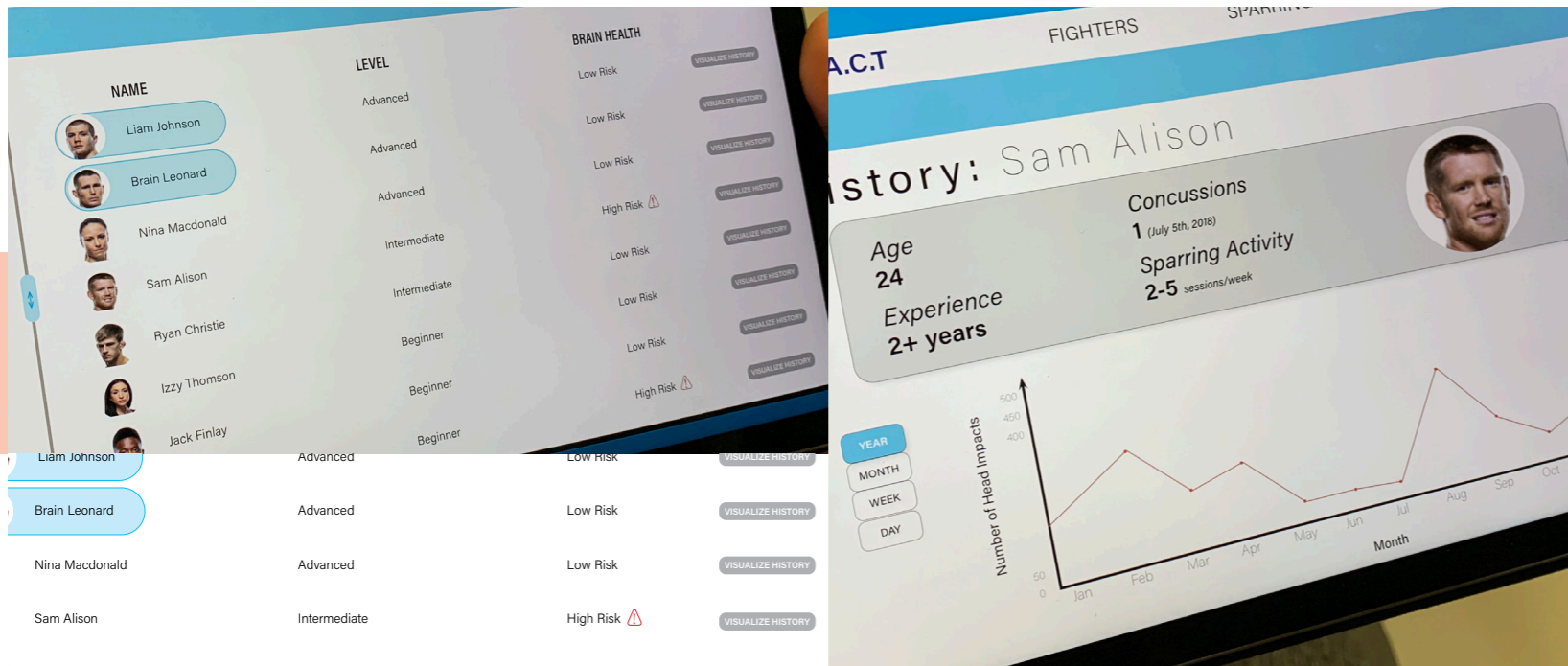
Boxer turns up to their local gym, ready for sparring practice



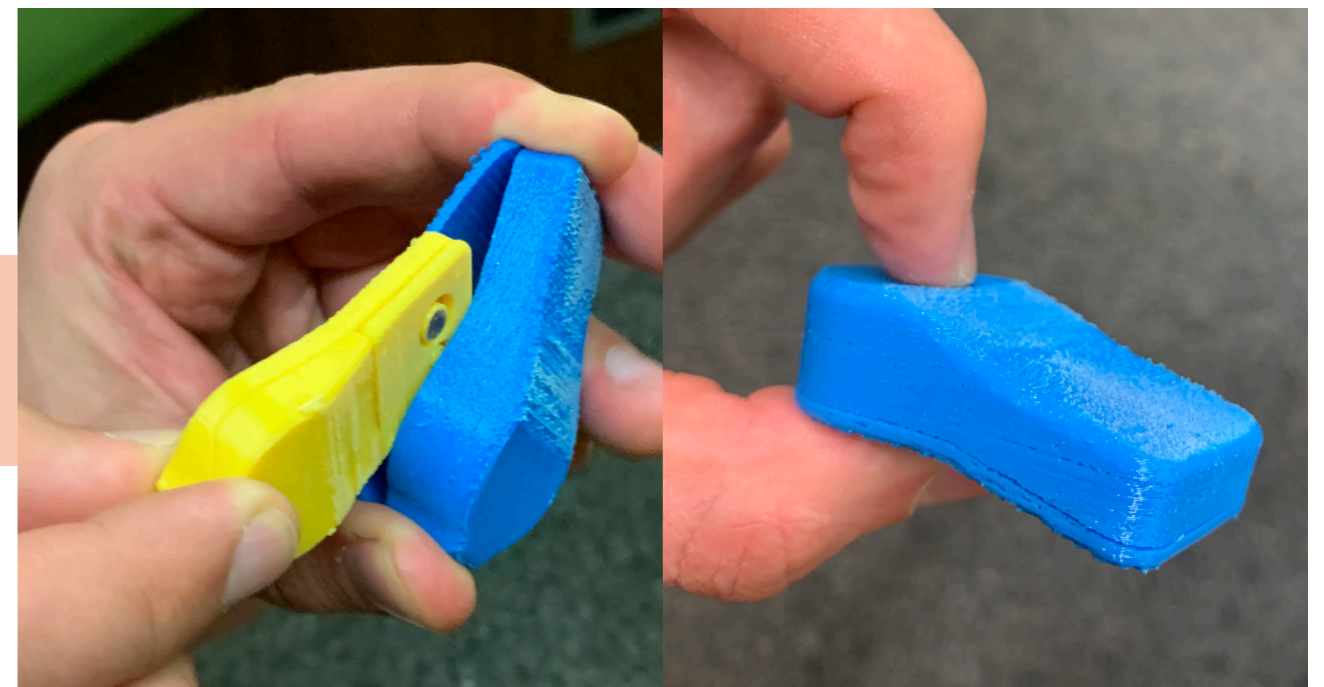
The P.A.C.T system is conveniently stored in the gym, ready for quick access.



He turns the on the P.A.C.T sensor, an LED light flashes notifying him it is on. The P.A.C.T is connected to a nearby laptop, phone or tablet via low energy bluetooth. The boxer's coach then selects the him and his opponent from a database of athletes who go to this gym. When a P.A.C.T sensor is connected, the coach assigns each specific sensor to each athlete. Meaning that data from this sparring session will be logged specifically to that fighter. After their sparring is over, the device can be used by another athlete.



The coach can see how each of their fighters have been fairing over time. If a boxer has been taking a lot of hard hits, the app can flag this to the coach. This gives the option for the coach to advise fighters to lay off sparring as they may be at risk of accumulating damage without letting their brain recover properly. The data from each sparring session is been uploaded to the cloud can be viewed in break downs by the day, week, month, year and so on. This is an additional selling point of the product for training as it means that boxers can see if their defence is improving or needs work based on how much their getting hit.



The protective casing's slit is pulled and the electronics enclosure fits snugly inside within the sleeve, elastically returning to its original position.



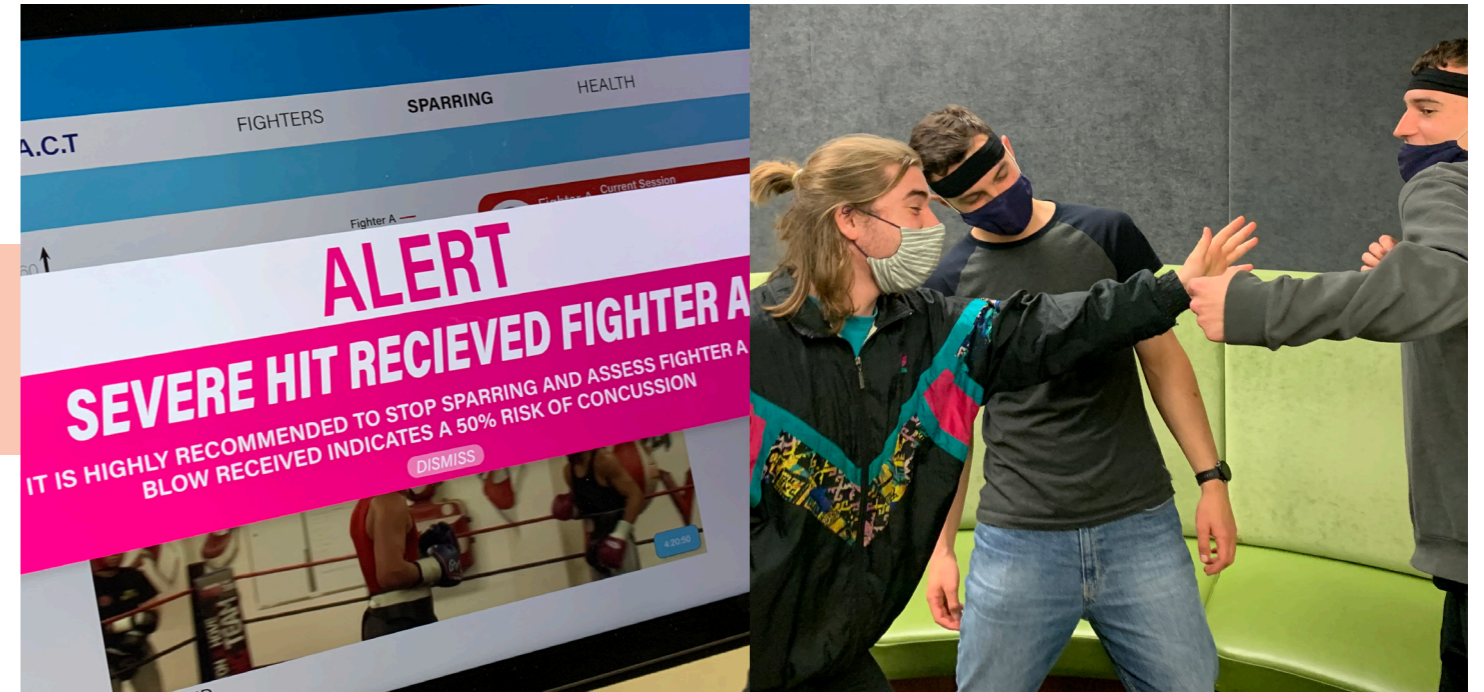
The boxer grabs a headband and puts it on. He slots the P.A.C.T sensor into the pouch at the back of the headband. Locating the sensor centrally at the back of the skull for optimal data readings and safest location.



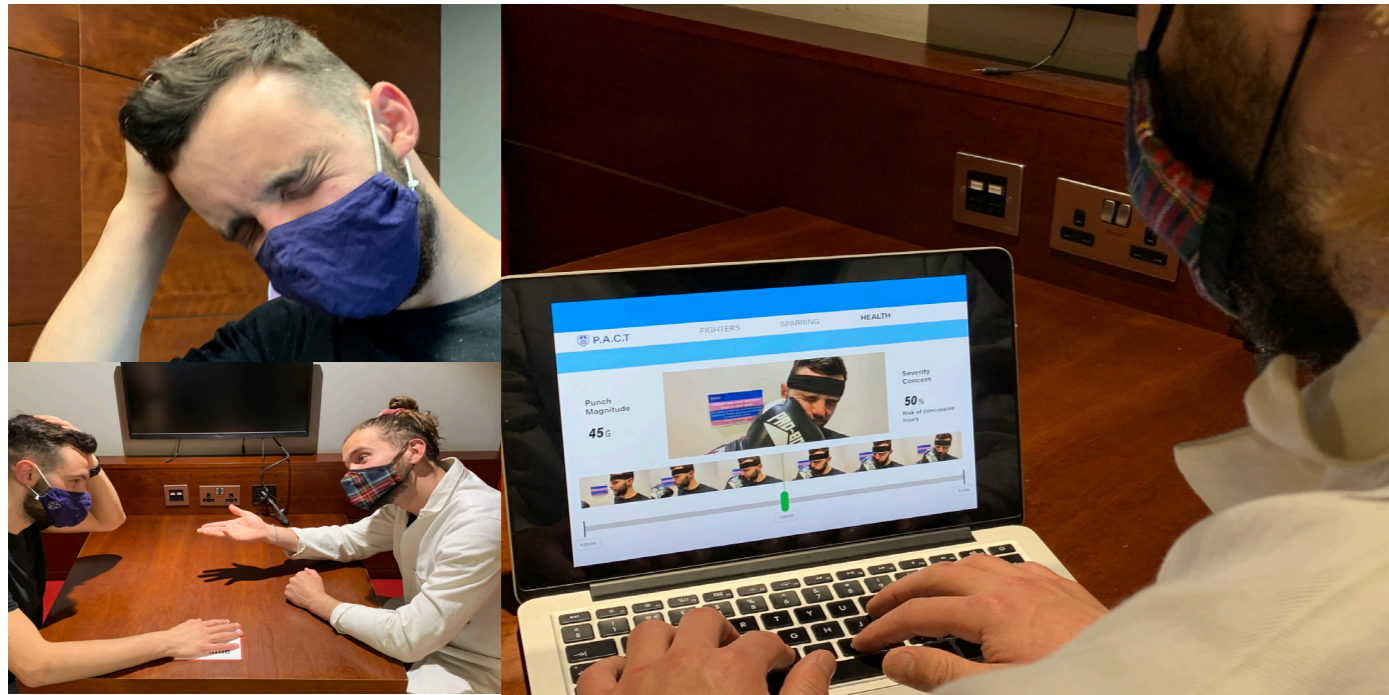
He finds an opponent willing to spar. Both athletes wear a P.A.C.T system and their coach decides to implement camera footage into record the session for training and in case of a brain injury, the footage will be helpful to for diagnosis and treatment later on



There is a clear skill difference between the boxer and his opponent. The opponent is landing several heavy shots in succession, causing the main boxer's head to be suddenly be jerked backwards in abrupt, dangerous accelerations.

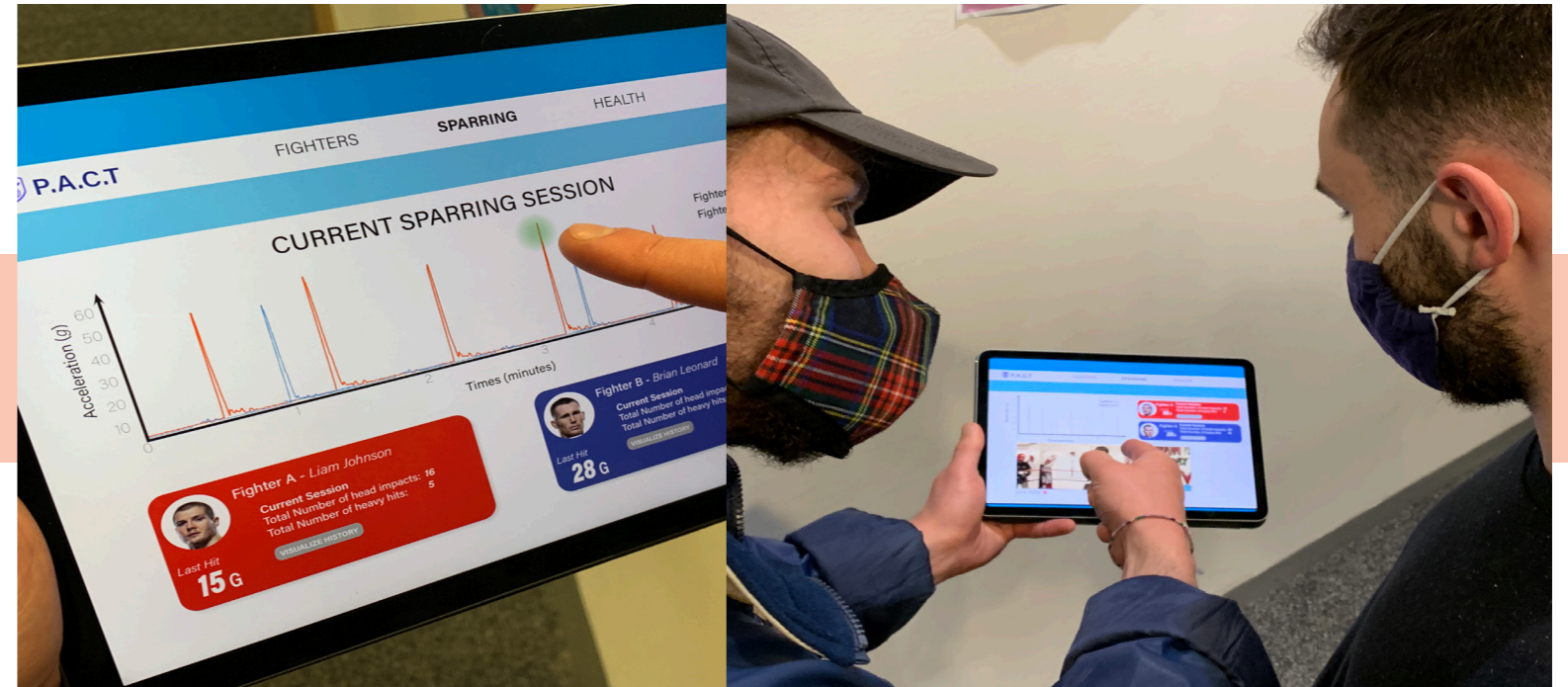


The P.A.C.T app alerts the coach to the danger the boxer is in. The coach decides that the sparring session should be stopped before he takes any more unnecessary blows. Despite taking damage, the boxer's situation has been prevented from getting worse. If he is concussed, taking further blows to the head has potential to amplify the severity of the brain injury.



The boxer may feel a little groggy for a few days with the minor symptoms of concussion. However, he is likely to make a much faster recovery and symptoms are not as severe having not taken any unnecessary further damage (where he may have done without coach intervention).

He may have gone straight back to sparring but P.A.C.T prompted the concussion assessment which meant a Dr could recommend the adequate treatment for an extended period of time (3-5 weeks) giving his brain ample time to recover and ultimately protecting his long term brain health.

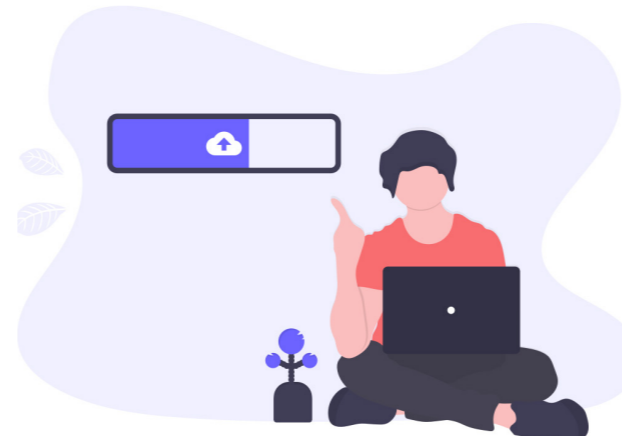
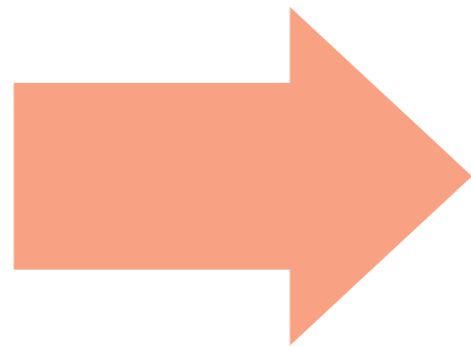


The punches and punch magnitudes of the sparring session is logged and uploaded to a cloud database to be referred back to at any time. The coach and the athlete can analyse the footage and pin point when the boxer is receiving powerful punches quickly rather than having to watch the entire sparring session. Thus, they can therefore identify weaknesses in the athletes game and make improvements

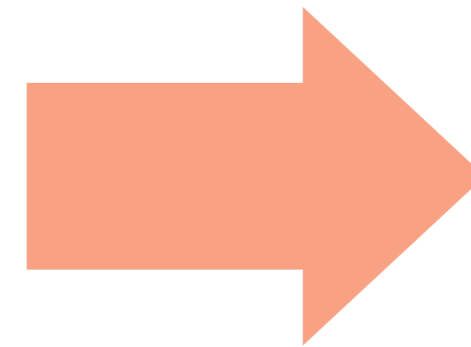
Data Transfer



Punch data received, recorded and temporarily stored during sparring session by computer/ tablet/phone



User ends session and has the option to upload all of the data on the cloud after the for future reference



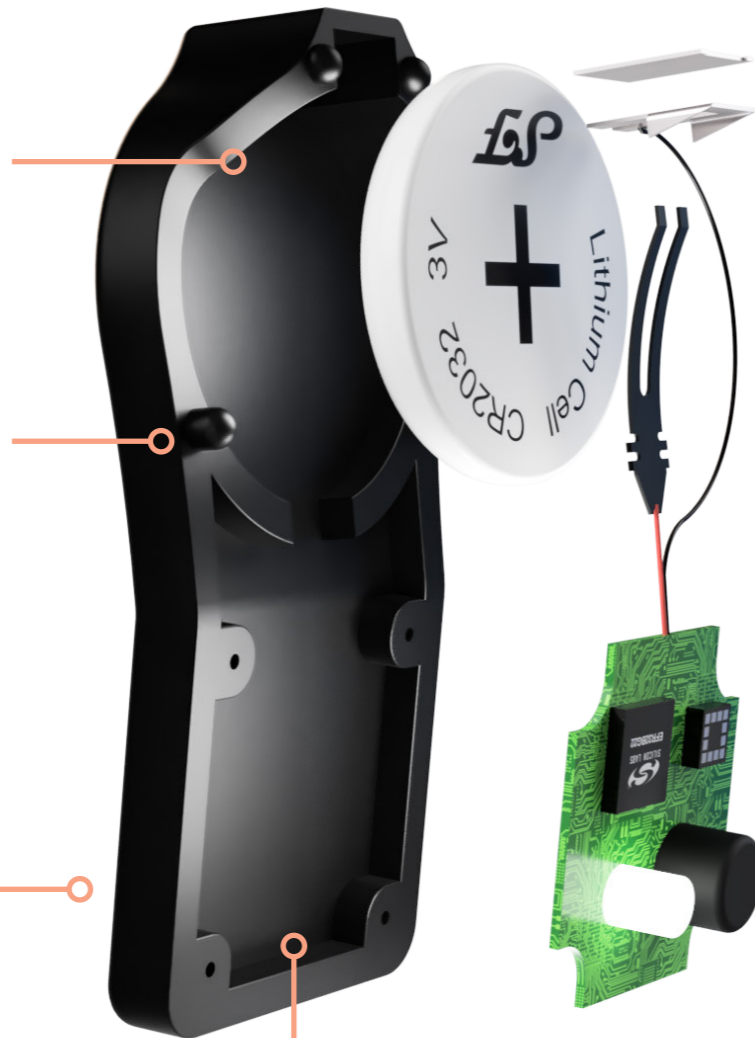
Computer/tablet/phone wipes the memory of the sparring session when app is closed but is accessible from the cloud at anytime

FURTHER PRODUCT DETAILS

Material choices were chosen based on their suitability for meeting previously defined functional criteria and was informed using Granta edupack software. Injection moulding was chosen for the manufacture of all of the plastic parts due to their intricacy forms and was confirmed as the most viable method for producing the product at minimal cost. Colour choices were not deemed particularly important for the user however, consideration was still taken with the black enclosure with engraved logo evoking professionalism and the bright blue of the protective casing making the product easily identifiable encase it was dropped in the gym.

Total Mass 0.0196kg
Predicted Selling Price £20 for a set of 4 units

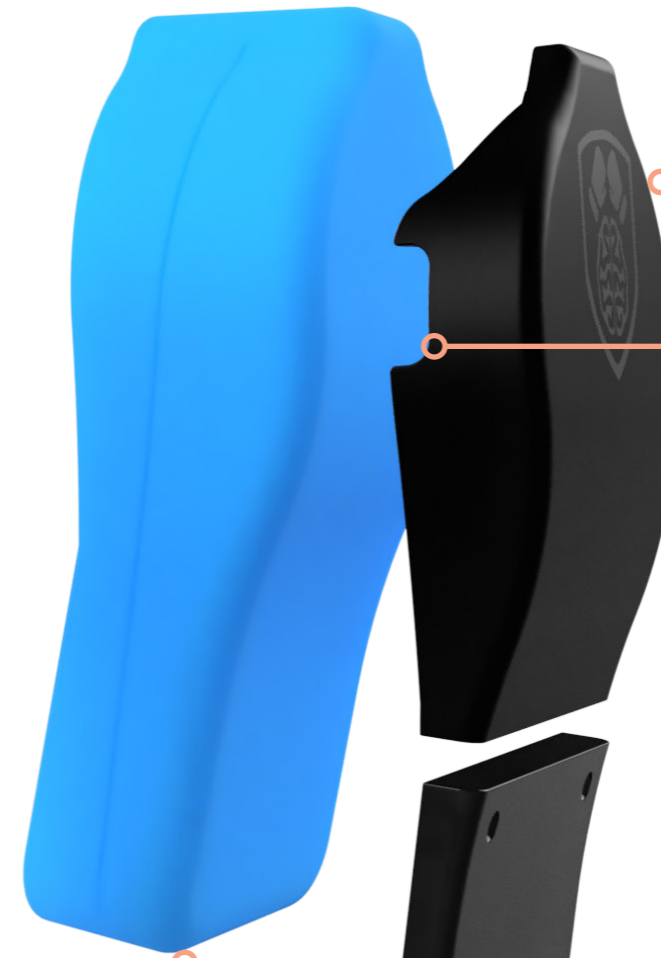
It was imperative that the CR2032 be kept secure due to the high accelerations and potential impacts it would be subject to. Hence, the walls were placed around its entire perimeter as well as protrusions on the underside of the press-fit lid



The press-fit interference fit was established after inputting material values and desired parameters into provided by an online press fit calculator with the interference choice was found to be 0.019mm.

The base and two part lid of the electronics enclosure are made from **high-impact ABS** plastic. Chosen for its low cost as well as exceptional impact and deformation resistance.

PCB cut to custom shape with snug fit around screw receivers



Laser engraved product logo

Cut out in press-fit lid gives space to allow for leverage to open. Suggested items include flat-head screw drivers, coins, Biro pens.

The fixed part of the lid is secured via M1x0.25-4mm (class 6H) countersink screws

Holes for LED and push button, push button was chosen specifically for its height as it allows for a slight protrusion of ~1mm making it easy and convenient to locate and press

Flexible Polyurethane rubber was chosen for its elasticity, exceptional compressive strength and impact absorbent qualities making it the most appropriate choice for protecting the boxers head and the electronics enclosure. It also has good tear strength which is beneficial as the slit in the casing will be open and closed frequently when inserting the enclosure. Elasticity was also key for this as well as for manufacture as the shape would need to be created using a sleeve mould set up where it the material needs to be flexible enough to be pulled out of the mould without being damaged.