HEADR
10 Page Summary

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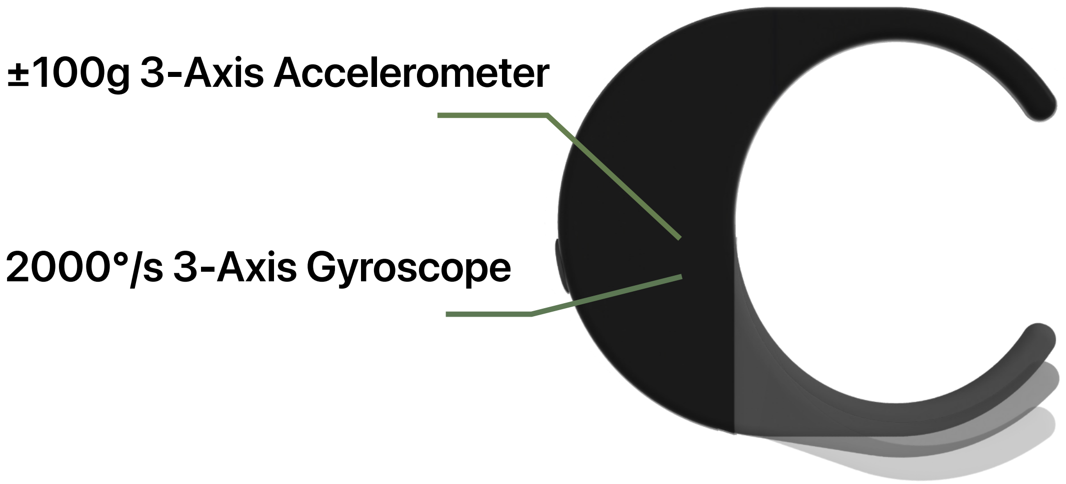
Product Overview

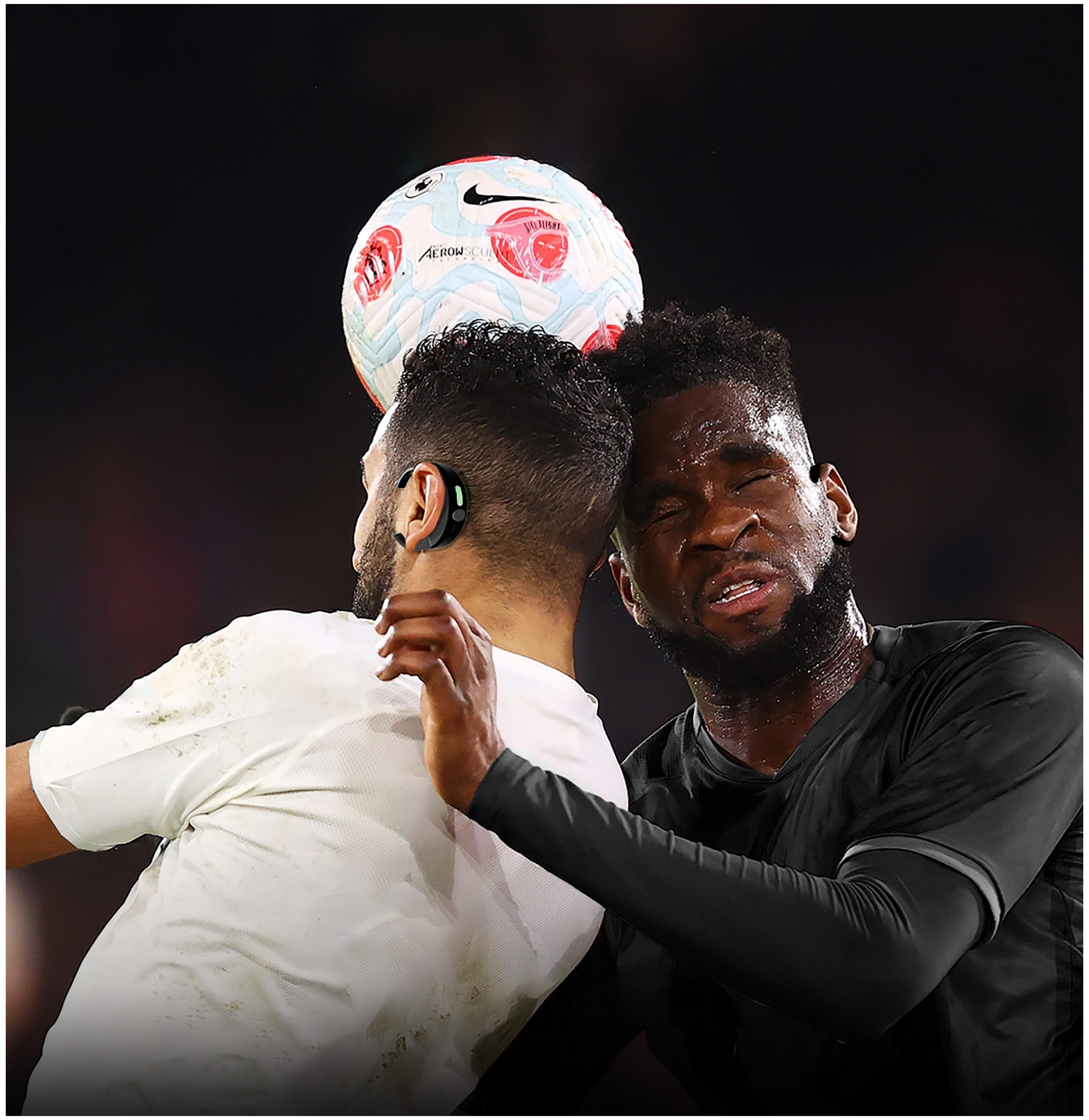
HEADR is a new wearable sensor designed to discreetly record the absolute linear and rotational accelerations of a footballer player's head whilst heading the ball in training and match play.

The product has been designed as a tool for quantifying heading exposure - in turn helping advance the medical studies into traumatic brain injury in football, and also building a clearer picture of the players overall health. It is hoped that gathering each players impact data over the span of their career would reveal trends which link to future brain disease diagnoses - in turn reducing the frequency of these in the future.



The Future of Impact Monitoring

The product has been designed with an expanding bottom leg which makes the product a one-size-fits-all solution. It is designed for footballers aged 16 and above, and it's intended buyer is the clubs themselves. They would buy a package of sensors for their squad, where the product simply slots into the pre-existing infrastructure in place for player data monitoring. For each header the player has, there is an associated level of g-force incident on the head as well as a rotational acceleration. These are stored in an app for later assessment by the teams medical professional and over time an impact 'passport' is formed.



The Problem

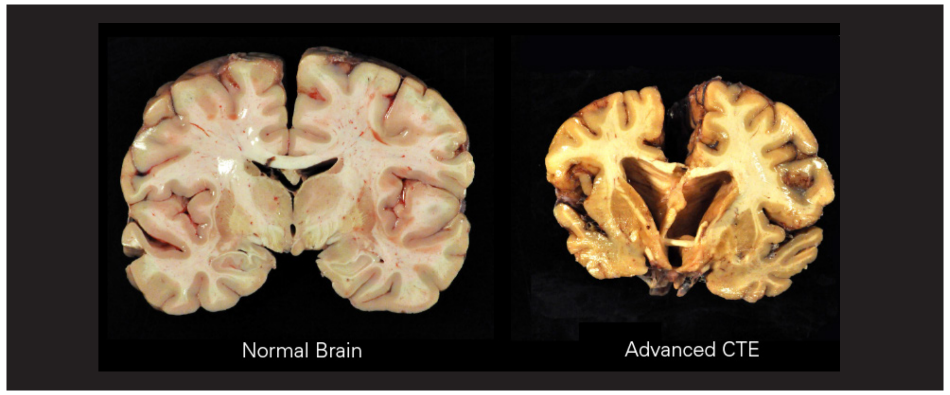
Chronic traumatic encephalopathy, or CTE, is a brain condition associated with development of diseases such as dementia, motor neuron or Parkinson's, and is caused by repeated blows to the head sustained over several years. Whilst it is normally associated with other contact sports such as rugby or boxing, CTE and its relation to football is now being put under a microscope due to the heightened media focus brought on by many high-profile dementia diagnoses of former footballers.

5%

1.6%

One report details that neurodegenerative disease was present in 5% of former footballers compared to just 1.6% of a matched general population control group.

Contact sports are slowly beginning to realise the hazards of concussion, however the dangers of the long term, sub-concussive heading impacts has garnered less attention. With the effects of heading not presenting themselves in football players until 30 or 40 years down the line, many believe the problem is insignificant, but it is one that is not going to disappear.

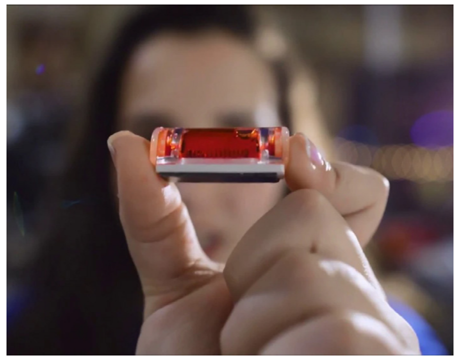


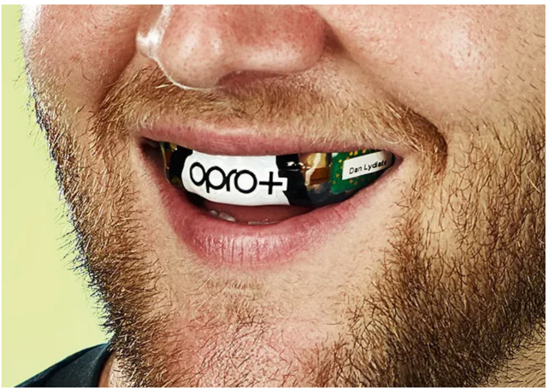
Current Solutions

There are several products currently on the market which relate to brain injury monitoring. None however have been proposed specifically for use in a football setting.

Current solutions such as independent sensor modules are designed to be attached to the headgear of boxers, cyclists, or rugby players, whilst headbands and mouthguards would likely be met with significant reluctance from the football players.

Many of these also put a heavy focus on solely concussion detection, and not long-term data gathering. One thing to note is that many devices boast a very small profile and rely on associated digital tools for communicating the impact data gathered by the internal sensors back to the user.





- **Smart headbands and mouthguard sensors would not be widely used in a football setting because it is too much of a shift in the culture for it to be widely accepted.**
- **Current solutions are bulky and obtrusive and give little to no instant feedback to the user.**
- **Many of the devices online are not actually commercially available, a lot of them look solely conceptual.**
- **Head impact products focus on concussion detection, and none specifically for use in football.**

Market Opportunity

Across all sports, there is an ever increasing desire for more in-depth player statistics and data capturing devices. Each team wants the edge over their opponent, and this is shown in the rise of wearable technology like GPS tracking vests.

A design which had the potential to appeal to this market and also tackle neurodegenerative disease was an early avenue of exploration.

Research

Speaking to Experts

Several links were established early in the project with various stakeholders within the world of traumatic brain injury. These experts were especially useful in guiding key design decisions.

Interviews were conducted with Dr John MacLean, the Scotland national team doctor and vice chair of the UEFA medical committee, Michael Marra MSP - someone campaigning in parliament to make football safer, and Dr Sally Tucker – an NHS surgeon and founder of charity Head for Change. There was also email correspondence with Dr William Stewart, one of the world's leading experts on brain injury.

Each of these discussions was extremely useful in generating some early ideas of which route to take the project. Some of the most important points taken from these talks were:

- **Currently there is no way to tell how much each player has headed the ball. Clubs are left to police themselves when adhering to heading guidelines.**
- **Football has slowly began to get it's act together with regards to concussion, but does not seem to want to address the problems that long term heading poses.**
- **Changes will be hard to implement in football - the sport is resistant to change at any level.**
- **The research into brain injury in football is still in it's infancy. A design could help in this area.**

Establishing a User Group

To generate appropriate feedback from those who actually play football, a user group was established of a mix of semi-professional and casual footballers. These users were referred to throughout the whole project, when feedback on certain design decisions was required. They also formed the basis of the design's user requirements.

> "
> **How many headers are too much?**
>
> **I don't really like the idea of wearing something but if it protects me it's worth it.**
>
> **I'll worry about the effects of heading later.**
>
> **Sometimes having too many products over-complicate football.**
> "

- **Any device that was an inconvenience to players would simply be discarded and not taken seriously by those in the sport.**
- **A design must be unobtrusive and look visually appealing - a sleek, modern design.**
- **All of the user group said they wouldn't voluntarily wear a product, it would require rule change to force them to wear it.**
- **The design would have to exist quietly in the background and not be intrusive to players.**

Online Research

Online journals relating to traumatic brain injury were investigated - particularly the 6 FIELD studies which are at the forefront of research into the potential risks of heading a ball. This was beneficial in establishing a basic understanding of the problem before speaking to experts about the project.

Creating a Working Brief

To conclude the discover stage of the project, a brief was formed out of the insights that were identified through research. This was referred to throughout the whole project.

An **unobtrusive** means of **quantifying heading exposure** for footballers. Allowing for the **data** to be compared to the limits set by respective football associations.

Some early project objectives included making a device that would was actually feasible for use in football, and developing a product which would address a real world issue - in this case Dementia prevention.

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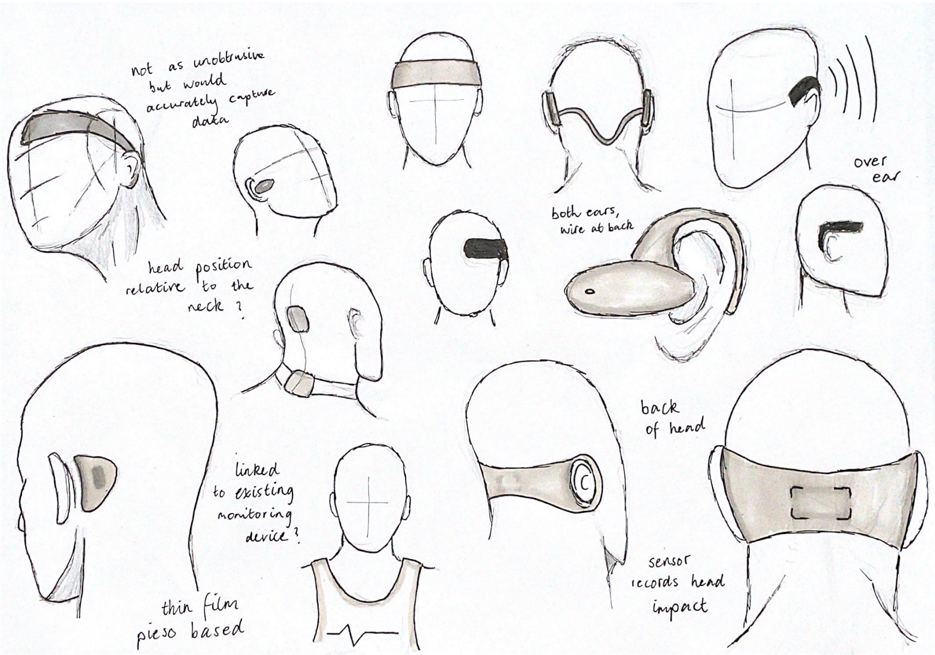
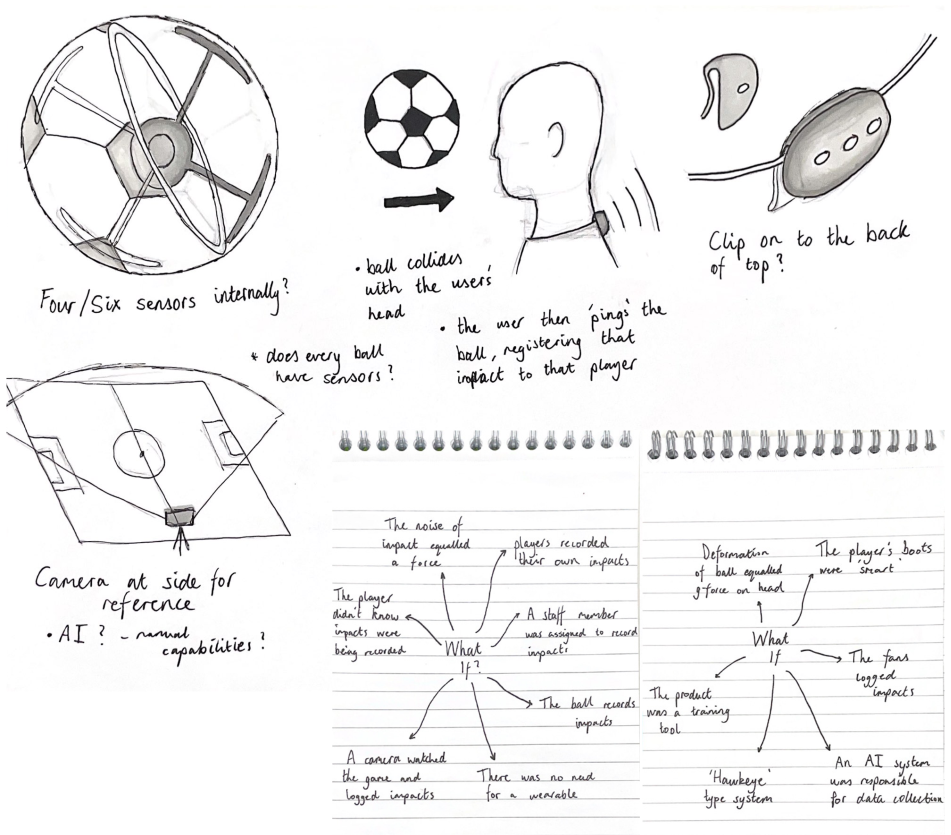
Concept Generation

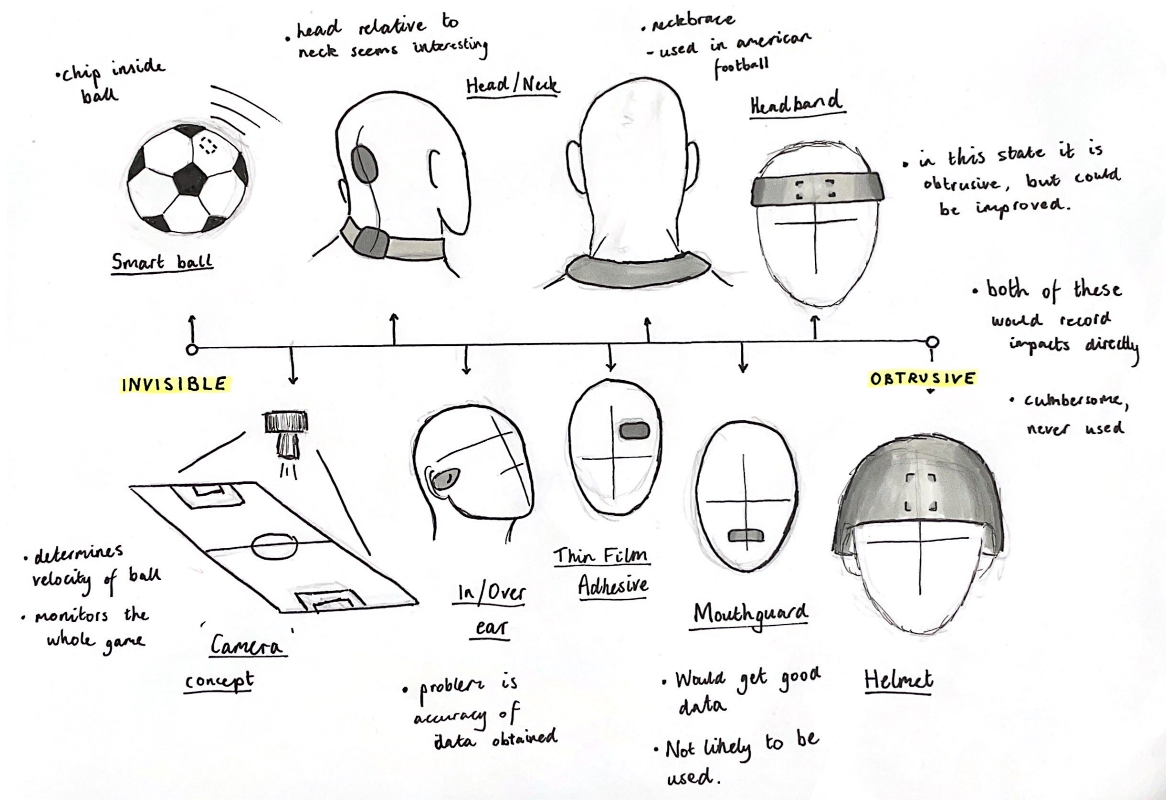
Initial Ideation

Whilst a wearable device seemed initially like the obvious route to take the project, it was not the only concept generated. Some ideas included a smart ball, an AI tracking system, or a training package which measured impacts whilst also improving the player.





The main challenged faced early in the concept generation process was the balance between obtrusive and completely 'invisible' designs. The further to the left of this scale meant the less reliable the impact data would potentially be and less personalised to each player. Too far right on the scale however would have too much effect on the user, even though the data would be robust.



	Smart Ball/Camera	Wearable	AI Smart Tracking	Training Tool With Impact Detection
Unobtrusiveness (x10)	9	6	10	5
Accurate Data (x9)	5	10	4	9
Safety (x8)	9	7	10	7
Comfort (x7)	9	7	10	7
Consumer Demand (x5)	3	9	7	10
Feasibility (x5)	4	8	2	6
Personal Interest (x3)	3	8	4	6
Affordability (x1)	2	6	2	5
TOTAL	316	370	345	339

Concept Evaluation Matrix

Prior to completing the evaluation matrix, each criteria's weighting had to be decided. This was a very important step, as it showed which key parameters were most influential in the proposed design.

Unobtrusiveness was determined to be the criteria with the highest weighting after the discussions in the early research stage, whilst things like affordability and personal interest were ranked the lowest.

Ultimately a wearable was selected and this was because it ranked consistently well through all criteria.

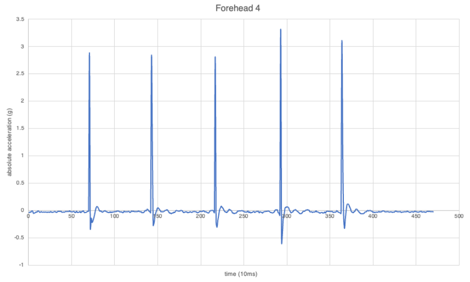
Impact Testing

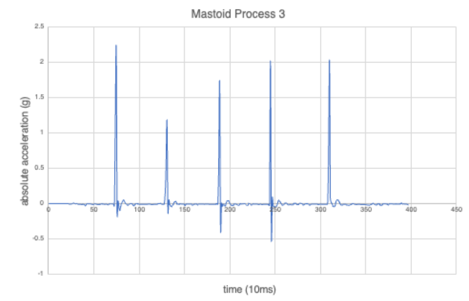
First Experimentation

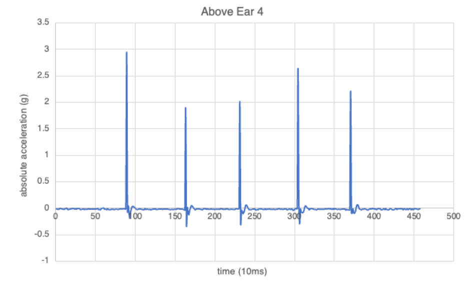
To validate that an acceleration response was actually viable from a sensor around the ear, impact testing was conducted with a ADXL335 accelerometer and Arduino Uno.

Three sensor locations were chosen: the forehead, above the ear on the side of the head and below the back of the ear on an area of the skull called the mastoid process.

The main aim of this testing was to first reveal whether an acceleration peak was achievable in this location, and hence work out it's relationship to the 'true' reading on the forehead.



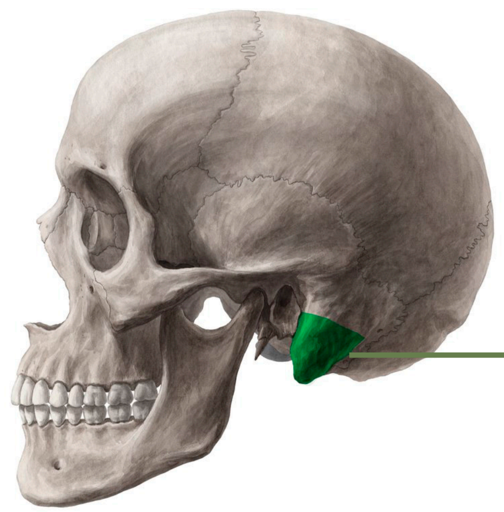


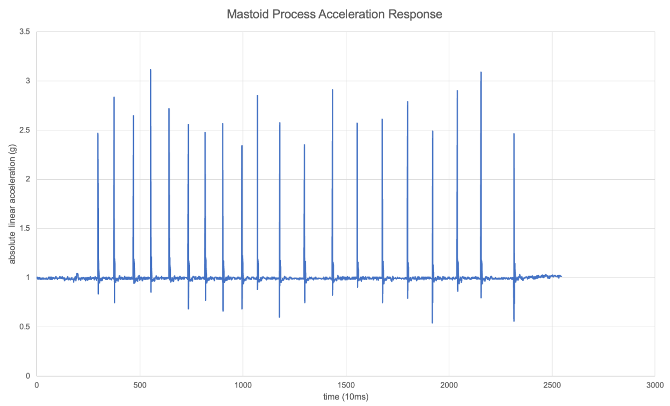


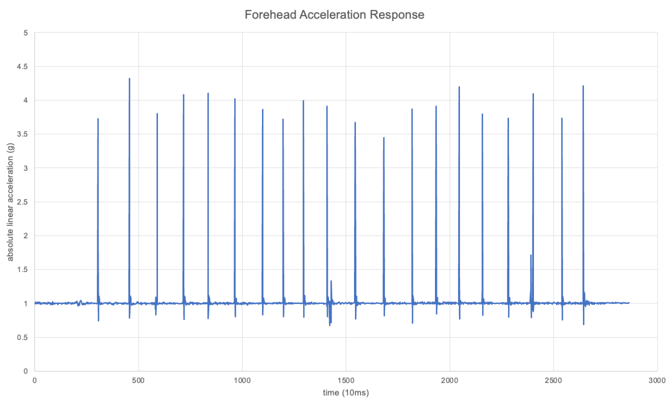
To find the absolute linear acceleration, the following formula was used to transform the raw data:

abs accel= $\sqrt{(a_x^2+a_y^2+a_z^2)}$

The first iteration of testing proved in theory that a clear peaked acceleration response could be achieved from a sensor at the side of the head around the ear.







Second Experimentation

A further iteration of impact testing was conducted to address the repeatability issues encountered in the first round.

This time a drop test was utilised which made impacts consistent - and an adhesive was used instead of a headband.

The 'Above Ear' readings were also scrapped in favour of focusing solely on the mastoid process - an area of the skull that is well defined in literature for sufficient sensor readings.

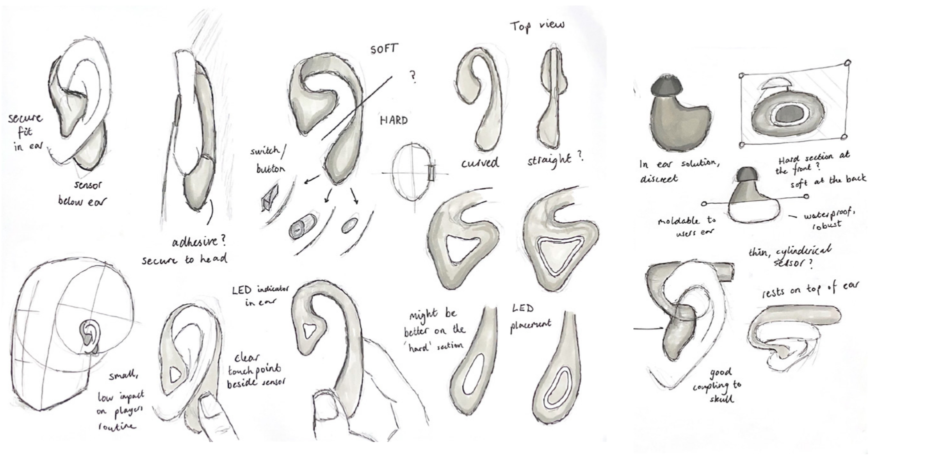
The drop test was a much more reliable means of gathering head impact data, and allowed for the percentage difference of the two locations to be determined.

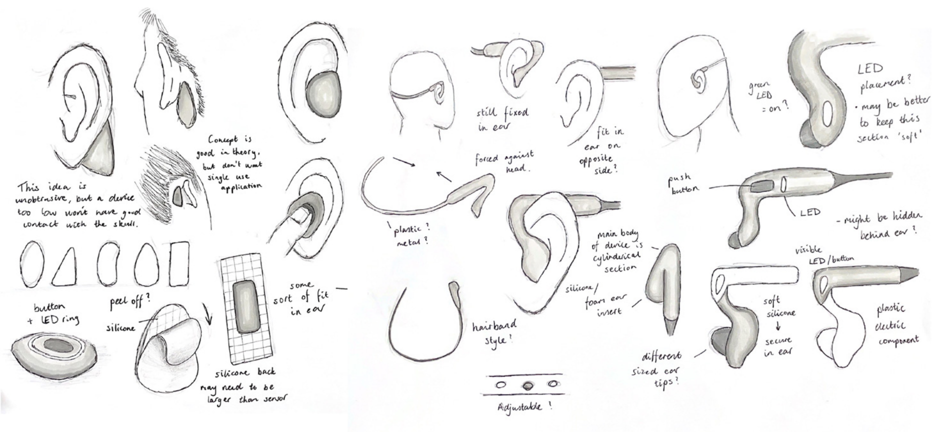
It was found that the absolute linear accelerations differed by approximately 38% between the forehead and mastoid process of the skull.

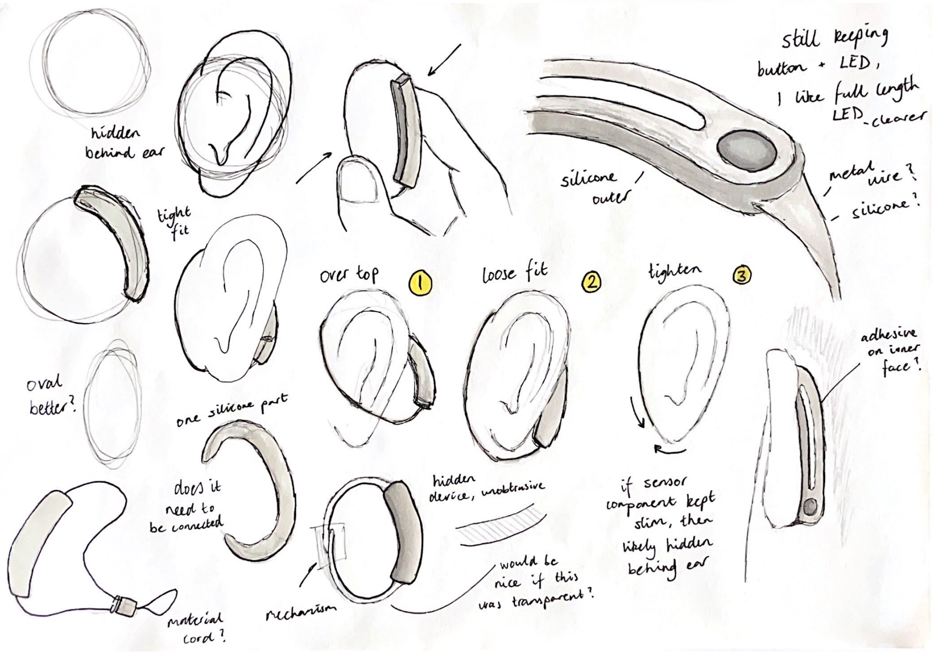
Design Development

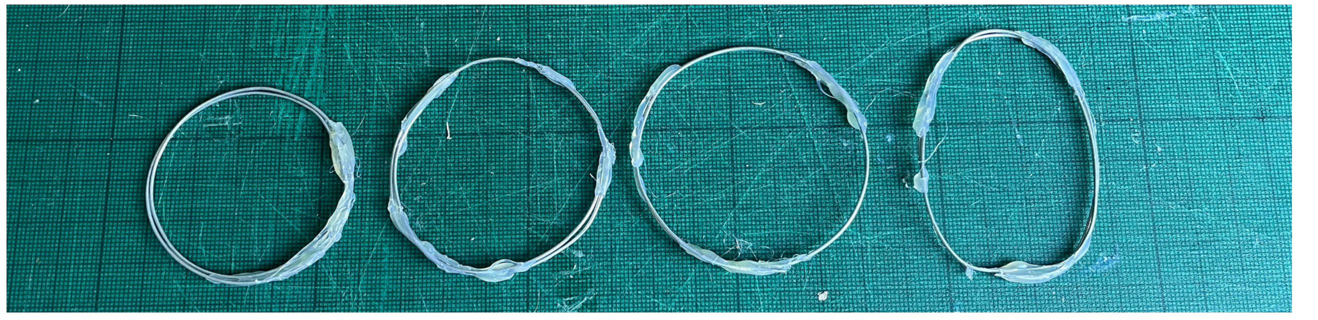
Ear Mounted Sensor

With it established that readings could be obtained from a design on the side of the head, there was lots of further exploration of ear mounted sensors.









Physical Making

Having the device secure and not liable to fall off during the football session was a hugely important requirement. Concepts which utilised an earphone style insert into the ear had to potential to affect the users hearing, so a hooking mechanism which latched on the earlobe and top of ear was devised.

This experimentation was carried out with basic wire and glue to get a sense of scale and it's associated fit that could be achieved with a circular or oval form.

Taking this forward, a small mass mimicking the sensor module was added to the back, made of the mouldable adhesive Sugru. When dried, this material is a strong and durable silicone with good flexing capabilities.

Issues were raised about the safety of a closed, tight concept like this, so an open, crescent shape was proposed - one that would stay securely in place in a fast-paced game yet also come off in the case of an accidental direct collision.

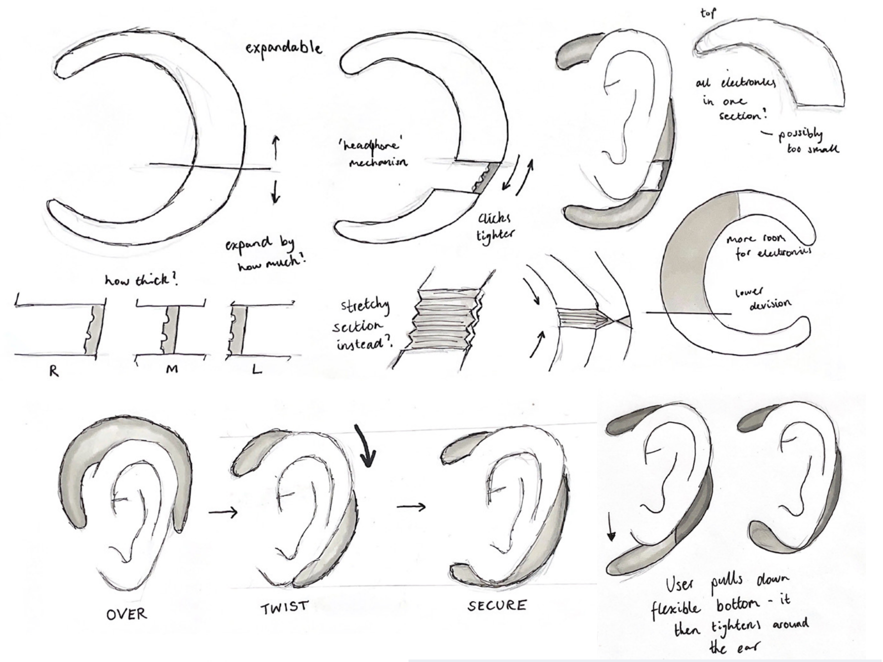
The outcome at this stage of development was a modern, stylish form and a unique way of attaching the sensor to the head.

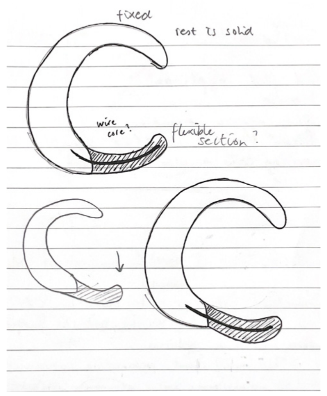
It's reserved appearance behind the ear gathered positive feedback from the user group, however the exact constraints imposed by electronics was not yet clear - more development was needed.

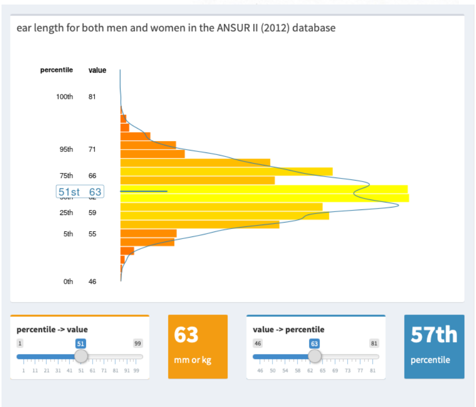
Design Development

Expanding Mechanism

The device had to be able to accommodate a wide range of ear shapes and sizes, so considerable time was spent refining a way of having the bottom leg be able to expand or contract.







The challenge with the expandable leg was creating a mechanism which deformed sufficiently over a long number of cycles, yet was still able to apply a light pressure to the ear lobe. The final prototyped mechanism was made of wire and Sugru and was deemed a comfortable, yet secure fit.

Design Iteration

There were several iterations of the design that were explored. Although the last few may appear the same, their differences came in the way they implemented the expanding leg mechanism.

Experimentation was conduced with the thickness of wire and it's internal fixing within the main body. For each 3D printed model, changes had to be made to the Fusion 360 CAD model to accommodate the different wire configuration.

Each iteration improved upon the previous version, until a physical model made to the correct dimensions of the real product was produced. The differences between this final model and the previous red coloured versions were very small - the most noticeable being its lengthened sensor module and smaller LED slit.

"

It's surprisingly secure.

I don't feel like it would get annoying I can hardly notice it.

I really like how it looks, I can see something like this actually being used.

The flexible leg is satisfying.

"

System Overview

Data Presentation

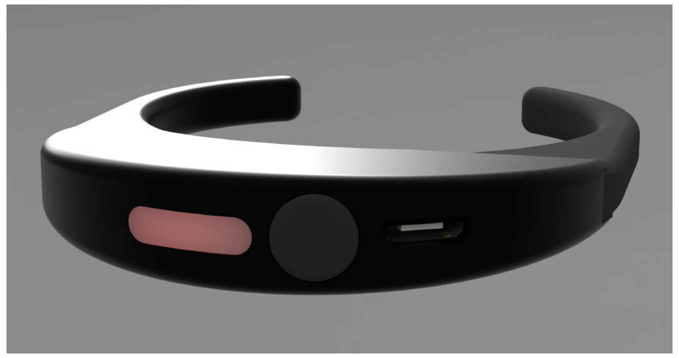
The product is designed to slot into existing tracking apps that players already use. The data is displayed as a bar graph denoting the frequency of impacts at each g-force level. Trends can then be identified across the whole squad.

Data Feedback

Speaking to players revealed that they would not actively want to check their own head impact data long-term. This insight was expected, because the footballer does not gain any real benefit from the data. It was then decided that the design should have two main users, each with different associated user journeys.

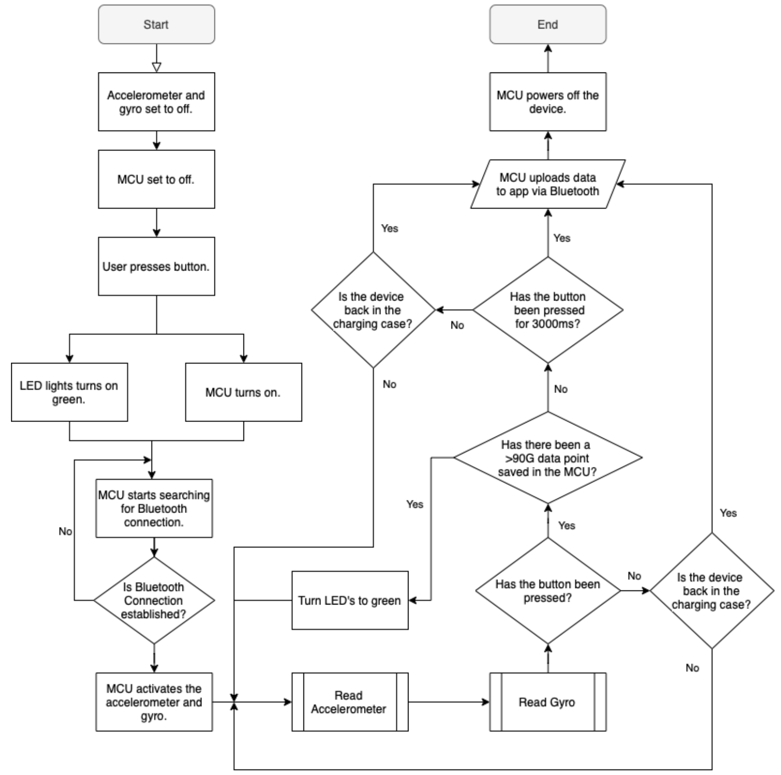
The footballer is the user who wears the device in a football session, while the 'analyst' is the one responsible for monitoring data and charging the device.

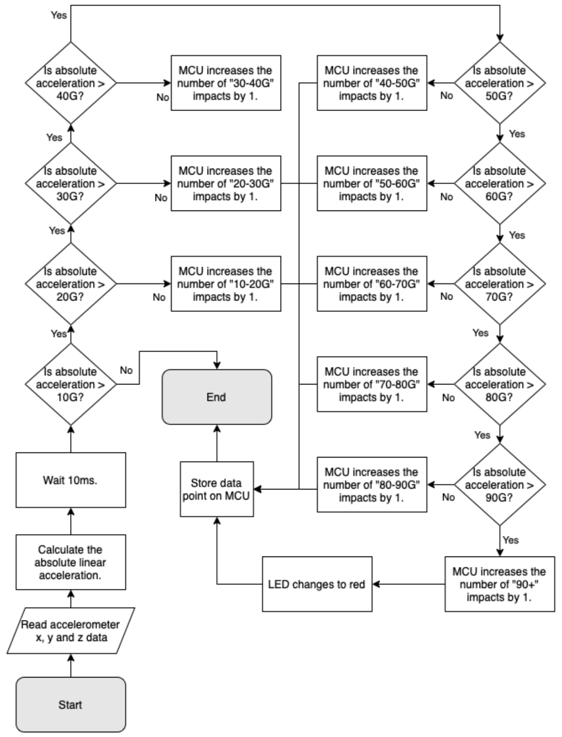
The data the product gathers is a linear and rotational acceleration for each header. The g-force range is 10g to 100g, and if an acceleration >90g is recorded, the LEDs change to red to indicate a concussive impact. It remains this way until acknowledged by the medical team when they press the button to turn it back to green.

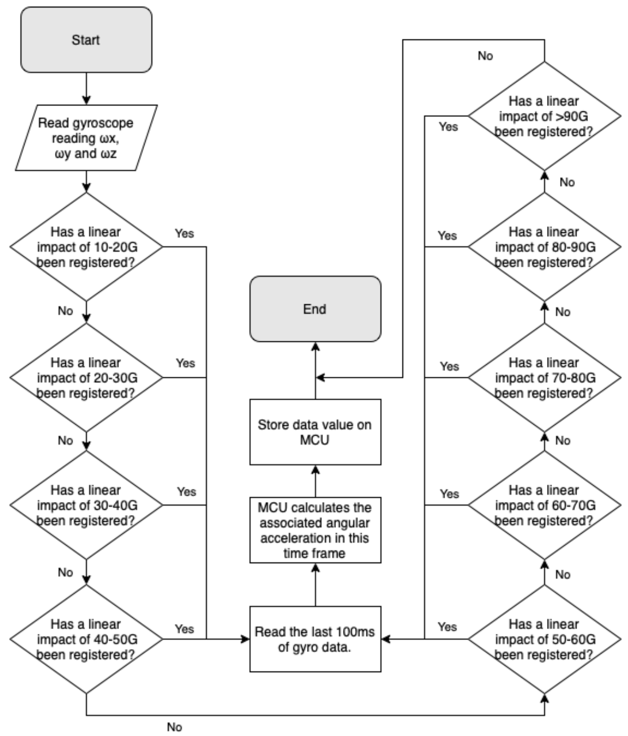


System Flowcharts

To understand the general logic of the system, flowcharts were constructed to help visualise the flow of information and data within the device.







Internal Components

Battery Capacity

Because of the small nature of the other components on the PCB, the battery was the component which dictated the overall size of the product. To choose the battery, the maximum time of operation was first determined.

Considering the longest possible football game including extra time gave approximately 150 minutes, and with an additional 30 minutes for safety gave 3 hours maximum time of operation.

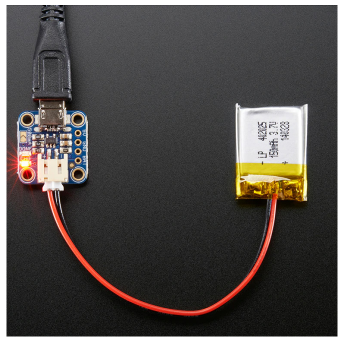
Component	Time of Operation (minutes)	Time of Operation (hours)	Current draw (mA)
Accelerometer	180	3	0.3
LED1	180	3	2
LED2	180	3	2
LED3	180	3	2
Bluetooth MCU	180	3	8.7
Gyroscope	180	3	0.85

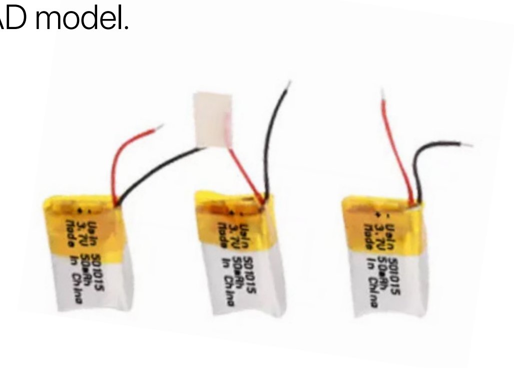
$$Q = It$$

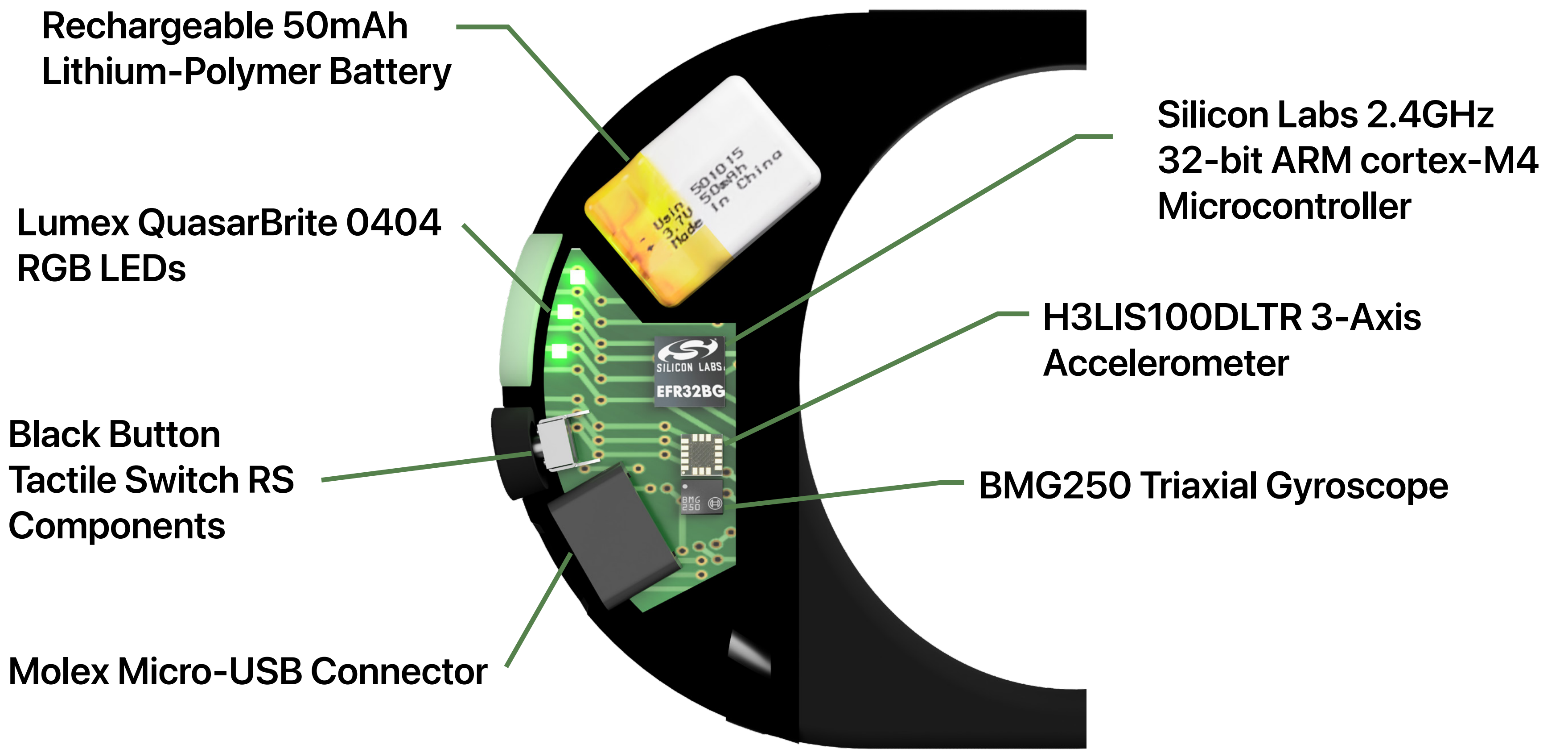
$$Q_{TOTAL} = Q_{Accel} + Q_{LEDs} + Q_{MCU} + Q_{Gyro}$$
$$= (3 * 0.3) + 3(3 * 2) + (3 * 8.7) + (3 * 0.85)$$
$$= 47.55\ mAh$$

A rechargeable 50mAh battery was then researched online. Coin cells and hearing aid batteries were first investigated however difficulty was had in sourcing a rechargeable battery which was to the desired dimensions. Some showed potential however they had to be manually inserted into a case in order to recharge them. This was not a part of the intended user journey as doing that 20 times for a full squad after every session would quickly get frustrating.

A small, rechargeable LiPo battery was then sourced which was satisfactory for the design. At only 10mm by 15mm, it only required minimal changes to the CAD model.







Chosen Electronics

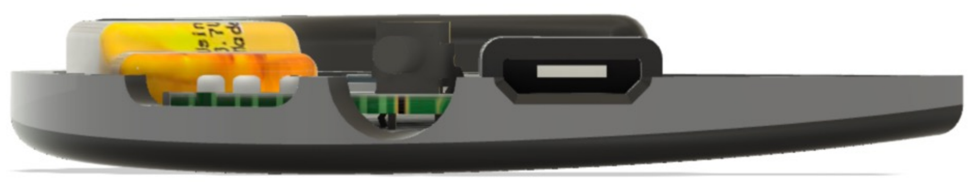
The printable circuit board contains components with high performance with very small footprints. The micro-USB connector is IP67 rated, meaning it is resistant to dust and water. The gyroscope and accelerometer use I²C serial interface to communicate with the microcontroller -identifying the bus protocol was consistent between each component was important when selecting sensors. Choosing a powerful microcontroller was also important because of the data it is processing while in use.

The components chosen for the product all had a very small PCB footprint and low current draw.

This allowed for the battery to be kept to a minimal size which in turn made the design's overall form slim and lightweight, weighing only 12.1g.

PCB Depth

The PCB is nested slightly deeper in the product in one side to ensure that the electronics are situated in the centre of the product. If the PCB was off-centre, then there would be errors in the associated data readings. Lowering it's depth also allowed for the push button, micro-USB port and LEDs to be in the centre of the back face of the design. The PCB is kept fixed through the mouldings on both of the bottom and top plastic casings. When closed, pressure is applied to keep it secure.

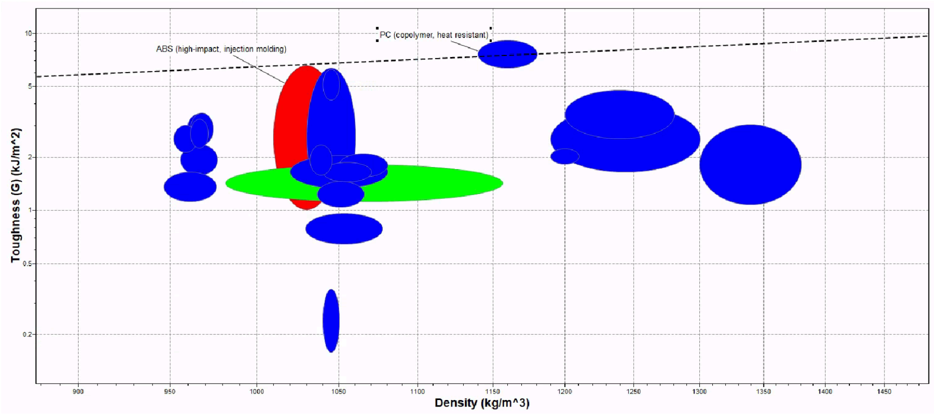


Manufacturing Details

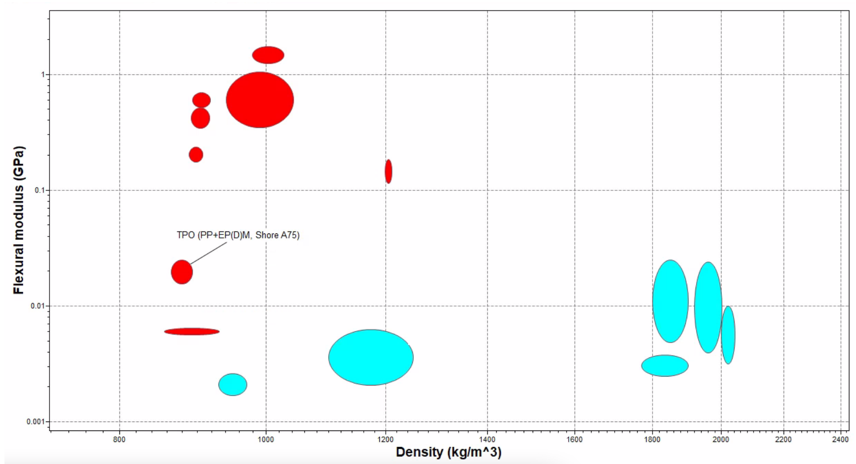
Material Selection

GRANTA EduPack was used to select an appropriate polymer for the top and bottom shell and a suitable elastomer for the expandable leg.

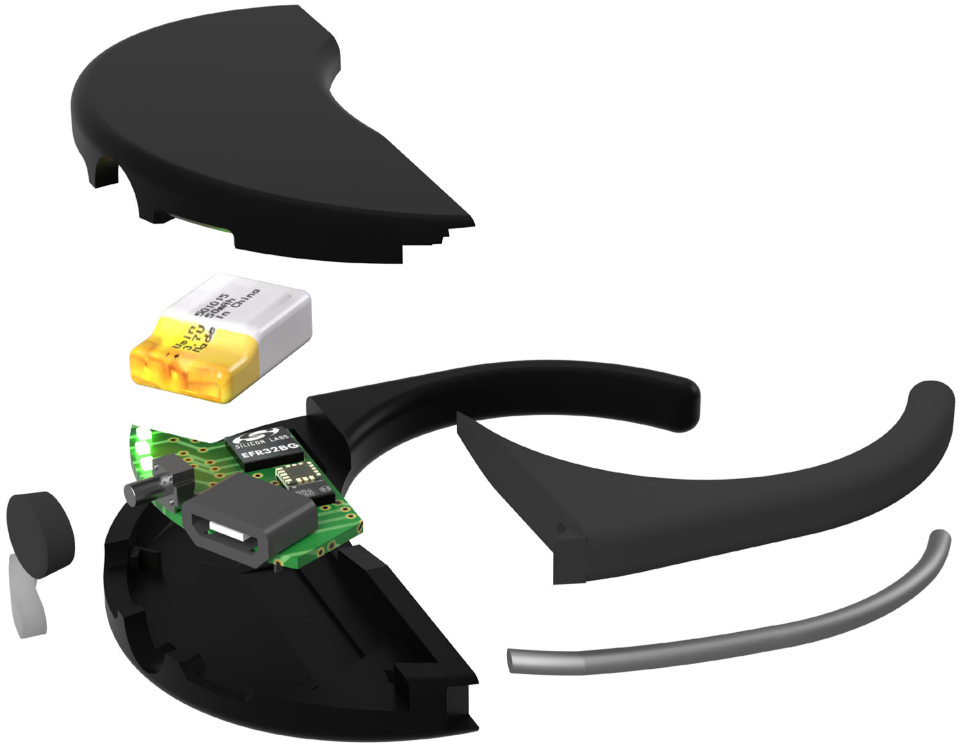
After imposing several limiting stages onto the list of polymers, high impact ABS was identified as the ideal material choice. Some of the restrictions included 'Excellent' injection moulding capabilities, and 'Excellent' fresh water, salt water and weak acids resistance.

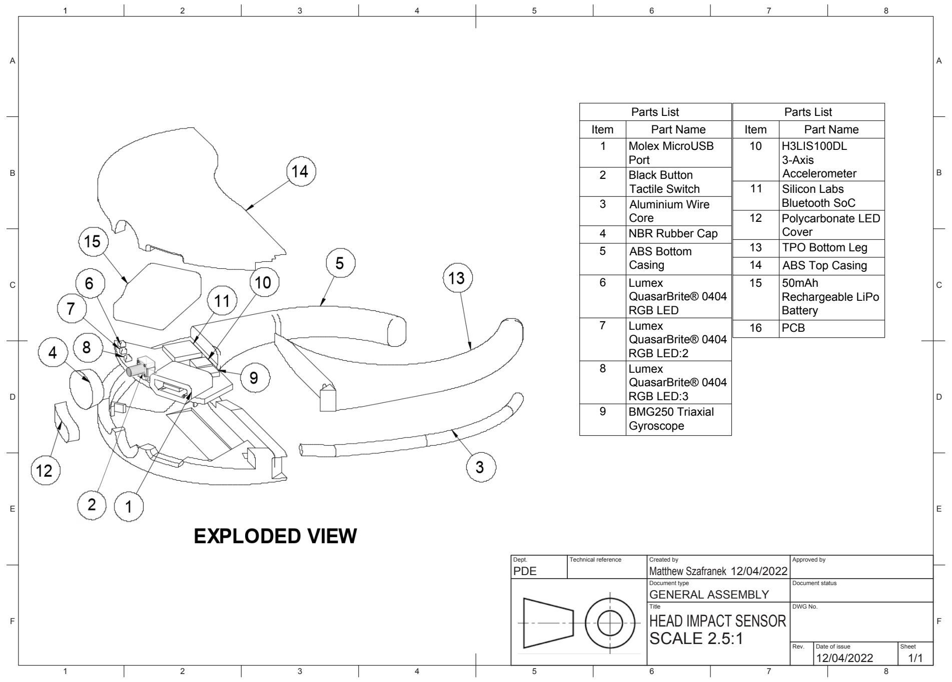


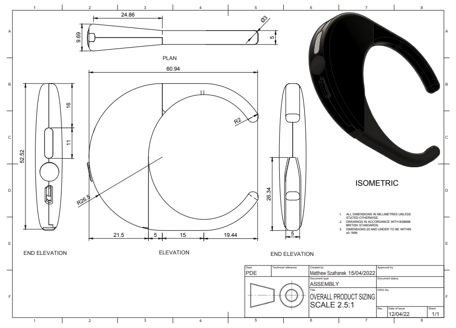
ABS is a light, high impact material which is widely used in an array of product applications. It is low cost, and perfect for mass manufacturing through injection moulding.

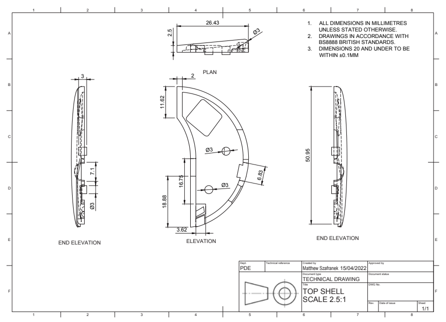


TPO Shore A75 was chosen as the elastomer material after considering each material's injection moulding capabilities, weatherability, and Shore A hardnesses. A material which had similar properties to Sugru was desired because of the large amount of positive feedback the physical prototype generated. Online research also revealed that ABS and TPO is typically used in two step injection moulding products.









Two Step Injection Mould

First, the two ABS shells will be produced in separate injection moulds. Good practise for injection moulding was adhered to - a consistent wall thickness of 2mm was ensured and draft angles included on both parts.

Next, the 2mm aluminium core of the expandable leg is then inserted into the product and bonded with a chemical adhesive to the bottom half. Once cured, this bottom section is involved in before the second shot of TPO elastomer is added.

Once the electronics are added to the design, the top half is attached to the main body with the help of an adhesive. Screw fasteners were considered for the product however a waterproof adhesive sealant was chosen because adding screws to the product would have involved making the form much bigger - in turn potentially making it unwearable for the user.