



BOXAID

Improved Boxing Headgear

Capstone Research Summary

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Introduction

The Problem

Historically the career of boxers has been riddled with health complications both during and past their time in the craft. With the most commonly seen issue being general head trauma, and concussions. Although thought to be a natural product of the sports nature, the common understanding is often misinterpreted.

People otherwise not involved with the sport would believe that the retained head trauma comes mainly during the actual fights, but that would be further from the case. Most retained injury accumulates from the months of training before fights, even while headgear is worn there is no protection from the kinetic energy that a punch provides.

The basis behind my capstone project's research and conception will be the design of a new form of boxing headgear that tackles the health risks faced during an athlete's career - and long after. Focusing on creating



01. Boxers sparring with the use of Headgear

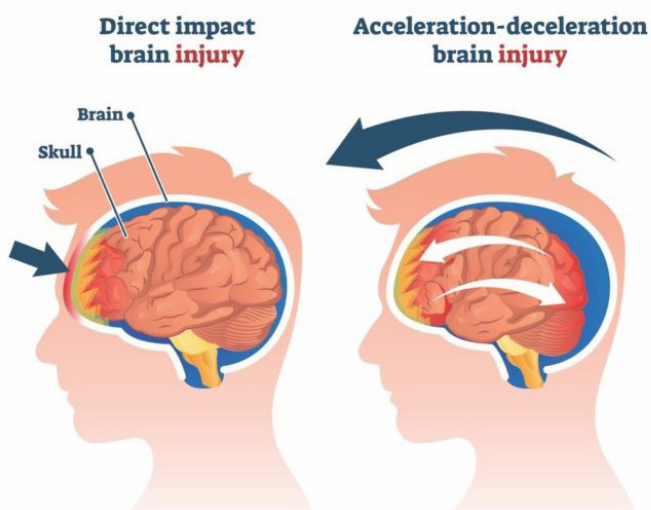
a proper level of safety for these athletes when they train is the main inspiration behind the concept, rather than the current false sense of security that modern age headgears provide [1], this way many careers and lives could be saved in the long run. The contents of this research summary include information discovered on topics including head trauma like concussion & CTE, the sport of boxing, protective padding in sports and other fields, and current market standards among others.

Definitions

The major areas of injury in the sport of boxing can be generalized into two distinct conditions, these being **Concussions** by way of a direct impact or one through acceleration and deceleration of the brain [2], and **CTE** through the accumulation of head trauma and repeated blows to the head [3]. Both of course working in tandem, as CTE can be a result of multiple concussions, these injuries are what flood the sport of boxing.

A **Concussion** is a type of traumatic brain injury - TBI - that is caused by a bump, blow, or jolt to the head that causes both the head and brain to move rapidly back and forth. Those sudden movements can cause the brain to move around or twist when in the skull, which can create chemical changes in the brain and even damage brain cells.

CTE - otherwise known as **Chronic Traumatic Encephalopathy** or “**Punch Drunk**” Syndrome - is considered a progressive and fatal brain disease associated with the repetition of traumatic brain injuries, including the likes of concussions and repeated blows to the head. It is also associated with the development of dementia.



02. Types of Concussions common in boxing



03. Comparison of Normal brain (left), and brain subject to CTE (right)

Background

According to the Association of Neurological Surgeons, 90% of boxers will retain a concussion at some point in their careers. This statistic is not for professional boxers alone but amateur boxers too, and youth are at an even greater risk when it comes to retaining a concussion. Feeling a sense of head trauma is something that most everyone who has been involved in sparring has experienced, all the while headgear is still being worn. Modern day boxing headgear - as it was in the past - holds no actual means of properly protecting against head trauma. The main purpose behind the design is to prevent any cuts and bruises, as during the earliest times of its conception boxers made very little financially per fight. This then forced them to take multiple fights in quick succession, so a single injury of any kind could deny them of any income and possibly set their careers back tremendously.

Head trauma, although common in boxing, sows the seeds of plenty of health complications that ultimately cut the careers of these athletes short. Boxers average out at around 5 years of work in their professional careers. As by that time they have accumulated so much head trauma that they are unable to compete any longer - unless they so choose to risk their health. Having any more than that is considered a blessing, and you generally see these same boxers adapt a more defensive approach in their bouts. This is because they have gotten to a point in their lives where age has caught up to them, and they might not be as explosive with a punch, or fast with their movements. They adapt so as to not only save their careers, but to save their health.

Research



Findings

To better find a solution to the issue at hand, research was taken in form of interviews, market research, and a more scientific relation of the sport both in the way of general physics and more refined medical study. Using interviews allowed for a way to have a first hand understanding of what boxers - both more professional, and “casual” - experienced in their sparring sessions and daily interactions with headgear. The market study centered more on the actual construction of headgear, the material usage, and the designs most commonly adopted by distributors and consumers. Lastly the medical study and research on the sports relationship with general physics provided context into how boxers hit and get hit, and how that affects their body inside and out [4].



04. Diagram presenting direct impact trauma effect from blow to the head after accumulated blows

The Boxer


The basis of the situation that I intend to solve with my capstone design can be simplified down to 3 main focuses; boxing headgear provides little to no actual support or padding to combat the risk of head trauma during sparring, the lifespan of said boxing headgear follows a linear economy where it ends as being waste, and a boxers career is cut short because of an accumulation of head trauma which can affect them later in life [5]. Now to understand why this issue should be solved, we must first look into a few key components behind why boxers do what they do.

The sport of boxing has been likened to that of a poor man's sport. However, it is not meant that there is no money to be made in the sport, but rather to succeed you must come from a situation in which a certain type of person is raised. There is a grittiness to the sport that draws in those who might not be the greatest in other conventional fields,



05. Patrick Day (2016) Passes away after Brain Injury

and instead look towards boxing as a form of income to support not only themselves but their families. Hence the reasoning behind why boxing gyms aren't these state of the art facilities, but instead these "run down" areas that almost exude the feeling of needing to persevere and succeed despite the odds.



From this idea of what the common boxer is - at least in part to those that pursue this as a career - we can then look at their practices during the sport. Unlike the past where boxers took hundreds of bouts in succession during their careers, the modern boxer may have only a few bouts a year. Spending most of their time training and preparing for the fights to come. In that time span one must spar to train their skills with a partner, whether that may be refining a more offensive style or tightening up a defense. Sparring allows for a closed environment where boxers can prepare for these upcoming bouts in their careers. Thus it is still designed to hold a level of danger and aggressiveness from both parties. Headgear is thus worn to protect the fighters, but only really from lacerations - hence most of the designs retaining raised cheekbones or different facial guards.

Interviews

The interviews conducted ranged from sport boxers (those who compete be it amateur or otherwise), doctors, coaches, and even the casual boxer who may compete in some sparring on a day to day basis. The reasoning behind these specific interviewee choices was so that there could be a vast array of information regarding certain aspects to the issue. Finding more specialized answers rather than vague ones.

The questions proposed to these sport and casual boxers were;

- i.) How often is your headgear being worn, and when?
- ii.) What are the issues you face with boxing headgear, if any?
- iii.) How many individual pieces of headgear do you own?
- iv.) When a headgear has grown old and worn how do you dispose/replace it?
- v.) Do you feel secure with the headgear on?
- vi.) Does the headgear soften any blows when in use?

Trey, Sport

i.) I really only wear it whenever I'm **sparring**, and that all depends on how frequent that really is. Sometimes you have a fight or two where it's required to wear it but thats on a case by case basis.

ii.) Well depending on the type of headgear, it can get really annoying in terms of **visibility**. Sometimes you can't exactly see everything and that can be a really big hassle when a

punch is coming from your side. But thats also why it's our own **personal headgear**, and we find what suits us.

iii.) I own **one**.

iv.) As far as I know all you can really do is **throw it out**, I'm pretty sure **they cant really be recycled** and no one wants an old worn out headgear.

v.) I mean in some ways sure, it does feel like I have something protecting my head. But

Interviews

reallistically it's **not supposed to "protect" my head**, it doesn't let me get cut up and that's what it was made to do.

vi.) Kinda, I guess? If I were to compare the amount of force it softens, to something like a bicycle knee pad, the knee pads got me beat.

Micheal, Sport

i.) How often I wear it is hard to say, since I might not be sparring the same amount everytime, but in a week a **good average would be three times a week**. The when is much simpler, **only when I spar**. You don't really need it on otherwise.

ii.) Not all company headgear is the same usually, so personally it's harder to find one that maybe **fits my head well**.

iii.) Only **one**.

iv.) I **throw it out, then buy a new one**. That's just what you do, there are ways to make them last longer though, like with how you clean and store it.

v.) It makes sure I **don't get cut** so in that

sense yea. But **sometimes I let myself get hit cause I have it on so it's a bad habit**.

vi.) Like I said before I let myself get hit when I have it on cause I **forget that it doesn't really protect me**, and believe me it **rarely softens anything**. It's up to us as **fighters to pull back on the actual punches**.

Jack, Casual

i.) **When I spar usually**, unless I'm just making sure it still fits, and not very often I guess since it only is ever on when the sparring is happening.

ii.) Sometimes **how tight it is on my head can be annoying**, but if it isn't tight then that can be a problem already. Being **too tight is really bad** since it'll hurt way too much.

iii.) I own only **one**.

iv.) I haven't been doing this too long so I'm not exactly sure honestly.

v.) I mean having that cushioned inside does feel kinda secure, it's **really nice when a**

Interviews

helmet feels comfortable to wear or doesn't mess with your skin.

vi.) A little bit I would say. It still does suck getting hit, but from what I've been told it's not supposed to really weaken any punches.

Allie, Casual

i.) When I'm sparring with someone else, and that's twice a week for me usually.ii.) My hair sometimes is hard to get through it cause it's too long, and it can get messy and tangled taking it off.

iii.) I have one.

iv.) Well I've only had 2 and I tried looking into recycling or donating my old one but it doesn't seem like thats a thing, so it's just sitting in my garage.

v.) Well it makes me feel like I'm wearing a bike helmet, I feel safe if I fall and hit my head with one of those, but I'd rather not. Same with boxing, I'd rather not be hit but if I do it feels somewhat safe.

vi.) So like I said with the feeling somewhat safe, the fact that it'll still hurt when I get hit is the reason why it's only somewhat.

WHATS BEEN GATHERED

General Consensus from boxers reveals that Headgear is only used when Sparring, and really doesnt provide any protection from the elements of head trauma

Aleks, Casual

i.) I wear mine when I spar, can't go in without it.

ii.) It feels like it doesn't really make the punches hurt less, I know it isn't made for that but it kind of sucks.

iii.) One headgear.

iv.) I just throw it out and get a new one, but they last pretty long.

v.) Well it's not heavy on my head so i can still move around, but sometimes it feels clunky even if it's still tight and not moving.

vi.) Yea like I said before I wish it did, but not really.

Interviews

The questions proposed to the coaches were;

- i.) What is the main purpose of boxing headgear?
- ii.) Do you think headgear could be improved in regards to a boxer's safety?
- iii.) What are the key aspects to a good piece of headgear?
- iv.) Is head trauma what is holding many of these professional boxing careers short?

Victor, Coach

- i.) It's to **prevent the head and face from getting any cuts, bruises**, any of those smaller sort of injuries, boxer's cant risk getting injured before a fight.
- ii.) Sure it **could be possible**, depends on how someone does it but it could be possible.
- iii.) Well it needs to **fit tight**, but **not so much that it hurts** when you wear it, it **shouldn't obstruct any vision** because then you create artificial blind spots, and you should be able to **move freely with it on**, it shouldn't slow you down.
- iv.) Well when you think about boxing and head injuries it sort of just goes together. It's something people have to recognize as a never changing fact. Don't get me wrong, I don't like it of course, people getting injured is never a good thing, but it happens in the

sport nonetheless. **Do I think it cuts careers short, 100%**. We see all kinds of great fighters lose out because of it, some of the all the greats have lost to boxings battle with it. But that's how it goes, that's boxing.

Joey, Coach

- i.) Headgear in boxing is **meant to stop you from getting any injuries to your face during sparring**.
- ii.) For sure, imagine if it stopped you from getting any blowback from punches, you wouldn't ever get concussions. **The olympics would probably bring them back**. Only reason they **got rid of it was cause it was safer to fight without it** apparently.

Interviews

iii.) I think it would have to be if it **fits good**, isn't too heavy, looks nice, and **doesn't block your line of sight**.

iv.) If we aren't talking about poor performance, then yeah probably. Eventually **the head can't take all that pressure and force**, and that's why you need a strong defence as a boxer and not just an offence.

Mac, Coach

i.) To **protect your head**, usually just from cuts.

ii.) If you mean to stop concussions, maybe. I haven't thought too much about it.

iii.) I guess just being a **nice fit**, not too heavy or weird to move in, and a **decent price** so you don't put a dent in your wallet.

iv.) I think it definitely is a factor to look at, sure it can't be the only reason but I wouldn't say it isn't one at all. **Looking into a solution would save a lot of careers** for sure.

WHATS BEEN GATHERED

Boxing Coaches have established that **Headgear was never meant to prevent head trauma in it's original design**

WHATS BEEN GATHERED

Exploring opportunities in **Headgear Improvement**, so as to prevent too much head trauma, has been expressed as possible and a good concept to follow

Interviews

The questions proposed to the doctors were;

- i.) Does the product of repeated blows in boxing lend towards head trauma?
- ii.) How severe could head trauma from contact sports get?
- iii.) Are there any distinct ways that head injuries could be avoided in the sport?
- iv.) It's been discovered that most head trauma accumulates during sparring, do you think a change in equipment could reduce this accumulation?

i.) When speaking on any sort of head trauma, the act of **taking on repeated blows to the head without proper protection, and even sometimes with protection, can lead to multiple cases of head trauma and injury.**

ii.) So I would say yes it does lend towards retaining some head trauma.

Well it can go so far as to be **fatal**, there have been multiple cases in history where athletes have passed away because of the severity of their head trauma.

iii.) Well sadly all that can really be said is **avoid getting hit**. That in of itself is **nigh' impossible**, and when talking about a **sport** like boxing it may aswell be further than **impossible**.

iv.) I do think that it could lead to

opportunities for success. I'm not too familiar with how equipment is made for sparring or even used in that case, but if there was a way to **reduce the accumulation gathered during sparring**, then you could see great success in providing a safer environment for these athletes.

i.) **Very much so**, I would have to say that the build up of all these impacts you take during the sport are just asking for a case in head trauma.

ii.) Besides death, it would probably be something like **CTE, Dementia**, I mean the list

Interviews

goes on. Almost anything you could think of, brain bleeding. There really is so much that could happen.

iii.) Besides not getting hit I suppose it would just be to have good head protection, but I don't think you really even wear any at all anymore.

iv.) Well then I suppose if its been recorded that sparring is where most of it accumulates, then having better equipment could help. Perhaps the headgear right now isn't strong enough to stop all the impact from punches, and demands a change in how its made.

WHATS BEEN GATHERED

Medical Professionals believe that if sparring is the setting in which most head trauma is accumulated, then following the process of creating better equipment for boxers to wear - specifically headware - would create a much safer environment and save many lives and careers

Insights

Gathering what was stated in the interviews it can be noted that the general consensus for boxing headgear is that it is mainly worn when sparring occurs, the common point of really only having one headgear, owners throw them out after the lifespan has reached its end, and the general care for it can be likened to a set amount of actions. When speaking in regards to the views of coaches, the main takeaways gathered were the consensus and understanding that all headgear in boxing holds the primary focus of providing protection from any lacerations, and bruising. This way fighters can avoid any facial injuries before fights that would otherwise complicate their work, and casual boxers avoid them as well. The interviews with medical professionals saw a better look into the actual connection that boxing has with head injuries and brain injuries. Being given insight into the actual specifics in terms of what would be the most commonly expected injuries and health risks in the sport - namely CTE, Dementia, the general Concussion, Brain Bleeding [6], etc... - allows for a better area of focus when designing for the headgear.



06. Nick Blackwell Suffering from Brain Bleeding (enlarged forehead)

Market Study

A piece of headgear that provides a better form of protection from head trauma in contact sports has always been in demand, and many avenues have been explored to create a possible solution. However boxing in this context has found no explorations in the avenue. Headgear in boxing has found little to no development in its design, instead the design has continued to value a form in which protection from lacerations and bruises is of more importance. The market standards for boxing headgear boils down to a leather like outside cover, with some sort of foam padding inside that is often cheap in material. However, protective padding and headgear redesigns in other contact sports have been already explored in great detail.

Everlast [7], Title [8], and Ringside [9] - among others - are suppliers and manufacturers of the commonly used and sold headgears by both professional and casual boxers. The aforementioned brands all use some sort of leather material on the outer portions of their headgears, that is wrapped over



07. Everlast boxing headgear - Velcro/clip fasteners



08. Title boxing headgear - Full Lace Fastening



09. Ringside Boxing "Facesaver" Headgear

Market Study

an interior of foam padding. The fastening systems used by the brands differ based on the headgear design, oftentimes having mixtures of lace, velcro, clips, and more.

Looking past the current boxing headgear market, protective padding has seen a great deal of exploration over the years. One such development in protective padding is D3O Goo [10]. The D3O goo is a non-newtonian substance that - like all other non-newtonian substances - hardens upon impact to absorb the kinetic energy that it comes into contact with. The newtons being free flowing until an impact is introduced with them allows for a malleable form that can still bend and be used for higher mobility activities.

Another exploration into the use of non-newtonian substances in padding and protective equipment, would be the 2nd Skull Protective Caps [11]. Much like the D3O Padding, it utilizes non-newtonian material



10. D3O Goo made into Knee Padding



11. 2nd Skull Cap Staple Protective Cap

Market Study

as padding to disperse and absorb impact. The difference being that the 2nd Skull Protective Cap is to be worn underneath the conventional sports helmet, so as to act like an extra protective layer. It's been noted to withstand up to 50 G's of impact force - in comparison the average boxer's punch is equivalent to 20 G's. Stouting a possible 20% reduction in impact, the 2nd Skull Protective Cap introduces the idea of using an extra accessory to assist in head protection.

Headgear in other contact sports has seen far greater explorations, specifically in sports like football where there is far more money circulating around. The Guardian Cap football helmet [12] is one such endeavor that has even seen use in the NFL training camps [13]. It is an accessory that is worn over top of the conventional football helmet, so as to protect the head from the risk of head trauma. Capable of reducing G-forces up to 33%, and fitting any sized helmet. It is said that since the outer shell has reduced forces transmitted, it can thus reduce the forces



12. Guardian Cap Football Helmet in use over general football helmet



13. Baltimore Ravens players using Guardian Cap during training

Market Study

sent to the head.

When looking at engineering opportunities with how headgear can be improved, another endeavor into football helmets can be cited. This being the VICIS football helmets, more specifically their Zero series of headgear. The helmets incorporate an impact absorbing layer that consists of columns that deform and buckle omnidirectionally, so as to allow the helmets to perform locally at the impact locations. The helmet offers 4 separate layers for protection [14]; an outer layer that compresses to absorb the rebound shock, polymer columns that move in different directions to absorb and reduce shock, a harder inside layer to prevent skull fractures and brain bleeds, and a layer of memory foam closest to the head to provide comfort.



14. VICIS Helmet with Indicated protective layers

Material Study

Discovery into alternative materials had led to the possibility of creating a circular economy for boxing headgear, rather than its current linear economy. Namely providing a recyclable form of the padding, and an otherwise biodegradable outer textile form. One such opportunity could be in polypropylene spunbond nonwoven textiles [15], that incorporate long-lasting anti-bacterial and anti-fungal properties. This way the natural human oils that come into contact with the headgear would not damage it in any way.



15. Clapure® Polypropylene spunbond nonwoven textile

Boxing headgear having originally been created by a sports goods manufacturer - who up until that point had only produced swimwear - to be capable of withstanding fifteen rounds of intense boxing training. With advancements from the original designs being generalized to; more localized padding of areas rather than whole singular pieces [16], and difference in design of the actual headgear shape. However, the issue is with how the actual “padding” barely provides any protection to the head. Possible alternatives



16. Localized “Padding” for modern day boxing headgear

Material Study

could lie within padding or protection that incorporates a honeycomb [17] form to act as an efficient energy absorber, and breathable material.

Another material with energy absorbing qualities, is that of Liquid crystal elastomers (LCEs) [18]. Capable of mimicking biological tissues, like that of shock-absorbing cartilage and contracting muscles. Capable of being produced as a foam, lattice shapes, and films, this material could create a strong level of protection for a layer of headgear protection.



17. Koroyde honeycomb structure within helmet



18. Liquid Crystal Elastomers (LCEs) without change in shape

Analysis


Synthesized

Looking at the information gathered throughout the span of researching, the key aspects that come into consideration are that of;

- i.) Sparring has been shown to be where most head trauma is accumulated, rather than the common expectation of it being during bouts.
- ii.) Boxing headgear currently provides little to no protection from the accumulation of head trauma, and is rather designed to prevent cuts and bruises.
- iii.) Headgear's lack of protection has caused it to be phased away from Olympic boxing, as it was shown to cause more damage than help.
- iv.) There is no way to recycle or reuse boxing headgear after it reaches the end of its lifespan because of how it consists of mixed materials - thus existing in a linear economy - creating more waste for the environment.



19. Sparring in boxing and the impact received



Taking these insights into consideration, an opportunity at finding a solution for these issues is left available. Constructing a new form of headgear to be used during training that allows for proper protection from the elements of boxing's heavy accumulation of head trauma. While also introducing different design options or material alternatives so that there may be a move towards a circular economy rather than the current linear one.

Brief



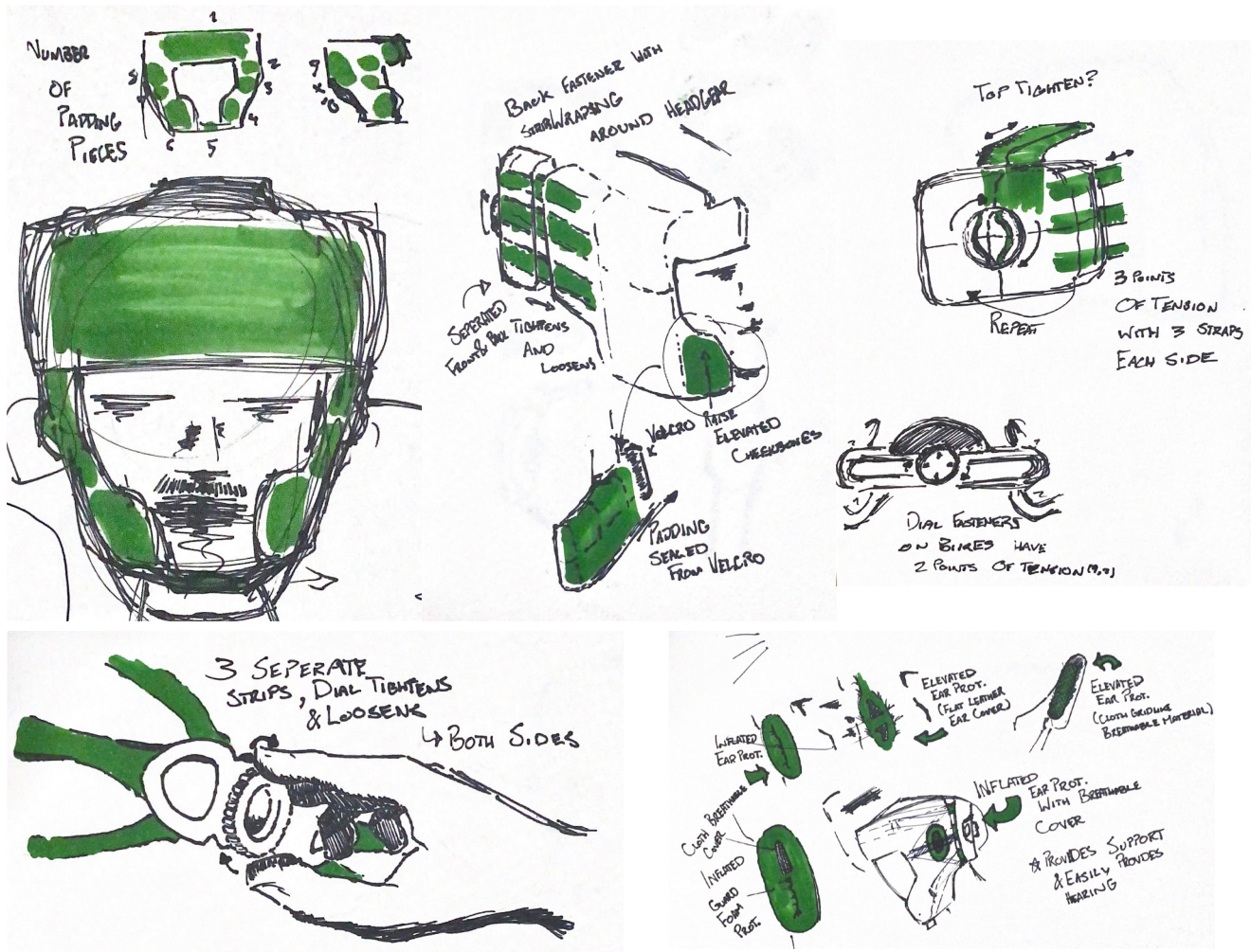
To design a new form of boxing headgear that is capable of providing an apt solution to the risk of head trauma, and injuries related (CTE, Concussions, Brain Bleeding, Dementia, etc...). While also creating a product that can be properly recycled to create a reduction in waste and push further a circular economy.

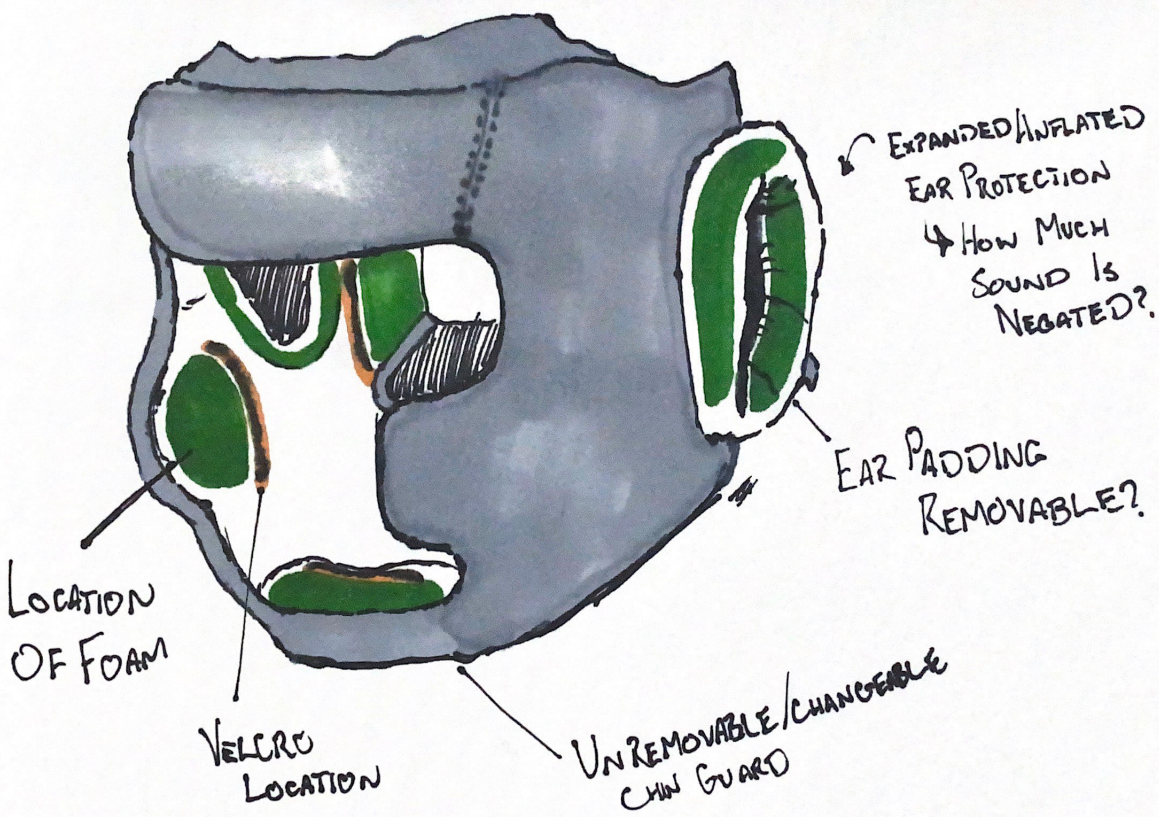
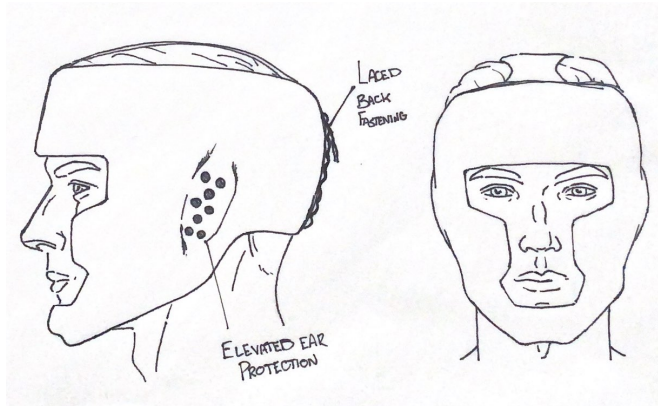
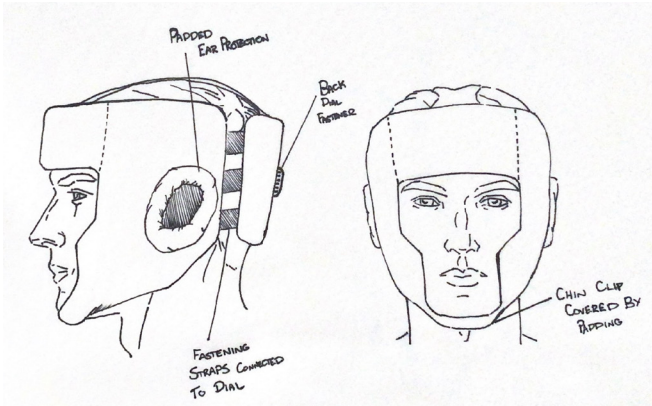
Having seen that studies reveal most of the injury building up throughout times of training, while fighters are wearing their headgear, it seems only natural to find a preventative measure for the issue. While also considering the fact that once a headgear has grown worn out and otherwise outlived its product lifespan, there are no ways to recycle it or specialized organizations that focus on finding ways to reuse boxing headgear in particular - what with the inability to easily remove padding from the form.

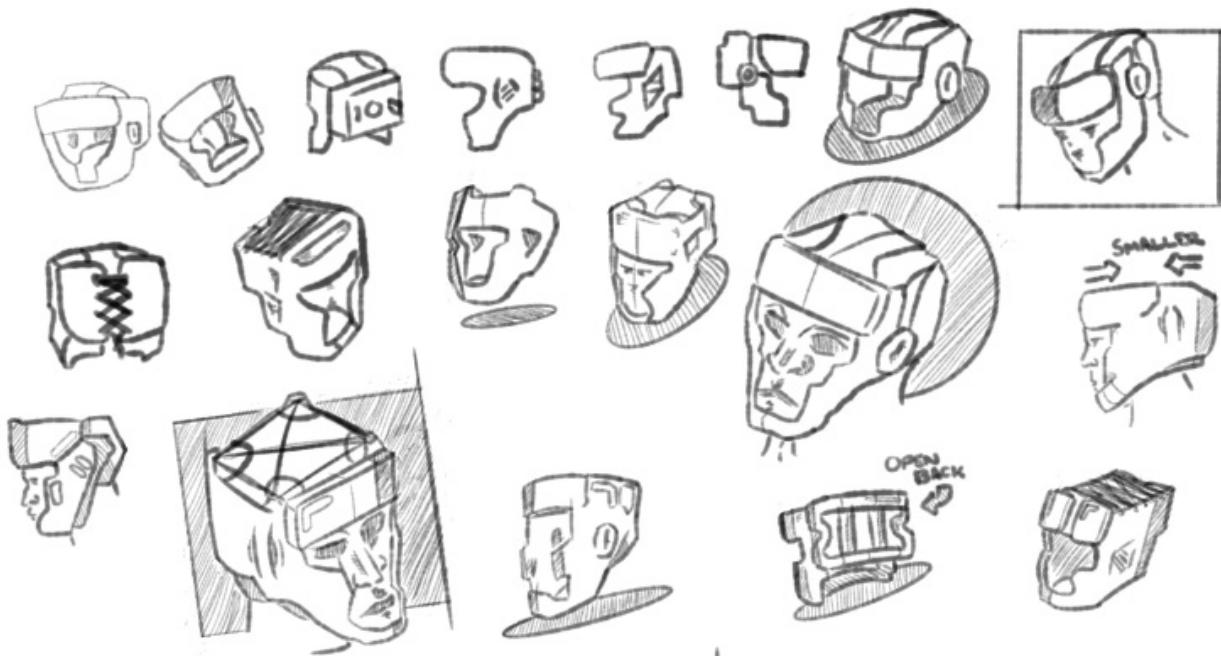
Concept

Sketching Ideation

During the sketching phase the most prominent designs and features conceived could be likened to a few key areas. These being the distribution of padding and protective locations within the headgear, forms that better suit focusing protection on specific areas, and possible alternatives to ear protection and fastening systems.







EXPANDED CUSHIONS

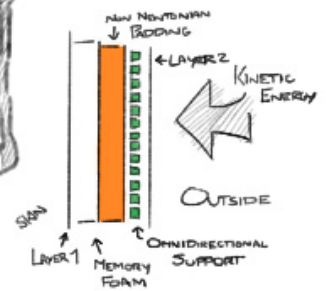


SMALLER



POINTS OF INTEREST

- » START LOOKING AT OMNIDIRECT SUPPORT (INNER STRUCTURE)
- > LAYERED CONCEPT IN SUPPORT



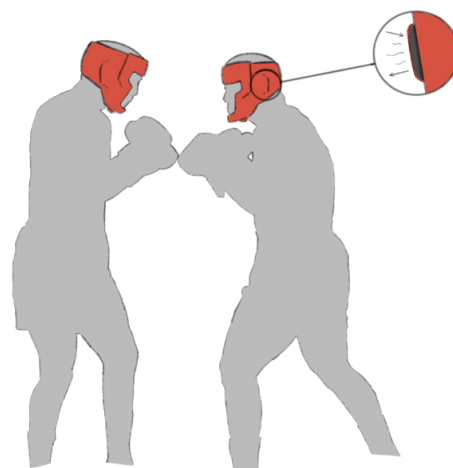
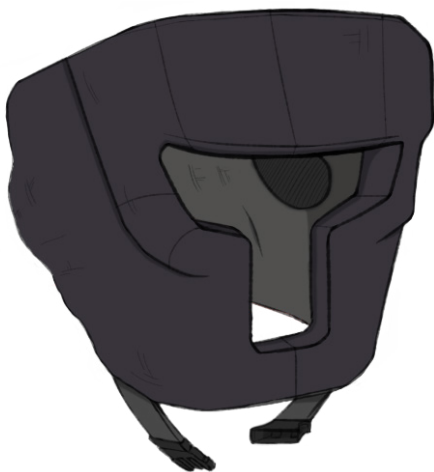
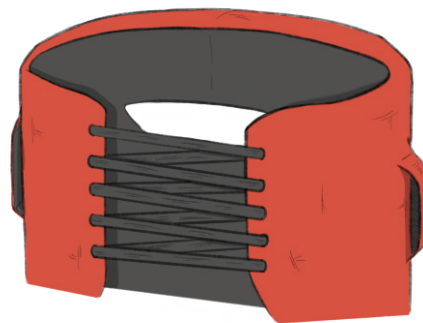
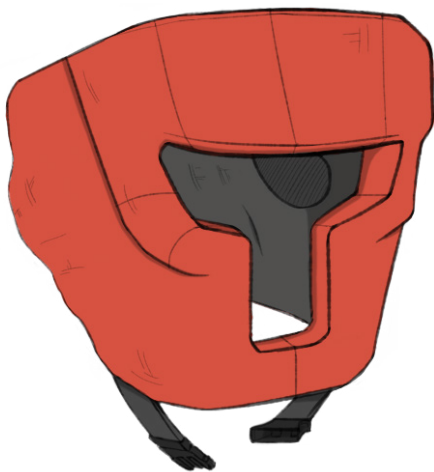
3 Concepts

The 3 Concepts that were explored in my process held key individual aspects to their designs. To elaborate, the red headgear uses a consistent size all around to ensure that no gloves catch along any part of it so as to loosen or move the headgear, the blue headgear would taken on characteristics of a larger facial cavity to allow for less blindspots but also incorporating enough larger pieces of padding to protect larger areas, lastly the green headgear would show prominent padding around areas susceptible to brain bleeds with almost protruding areas of padding in those areas.



Final Design Concept

The final concept for my headgear design incorporates the protrusions located around areas most commonly affected by fatal injuries like brain bleeds, so as to ensure that a boxers career can be extended free of any major life altering injuries. Also utilizing an open back ear cavity to allow for better hearing during sparring sessions. Keeping the fastening system conventional with its lace back and chin clip feature will allow for it to fit comfortably and snug on the wearers head.



Model Prototyping

The early phase of model prototyping consisted of the development of the padding systems and their interaction with an anthropomorphic headform. Early looks into the padding and the general headgear consisted of cardboard models that fit around the headform, and 5:1 scale models [20] of the support systems.

The cardboard half of the headgear form was meant to show how the inner padding would be layered, as well as how the features would accommodate to the human head when worn. Specifically how the ear protection would work in that regard, as well as how far the protrusions would come out from the base layer of the headgear. Smaller scale support systems were also made through 3D printing with Thermoplastic polyurethane (TPU) filament [21] to test whether or not the forms were capable of moving omnidirectionally under pressure and staying intact.



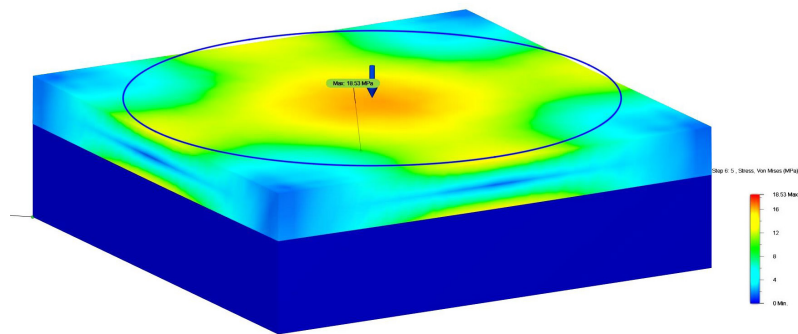
20. Cardboard Validation Models of Helmet Cross-Section and Supports



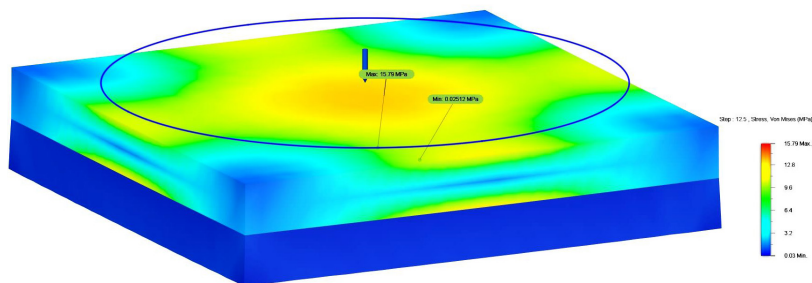
21. 3D Printed Support System Tests - TPU

Validation

The process of testing the material strengths to ensure their ability to withstand and disperse the impact of a punch during sparring was done through a series of Finite Element Analysis' (FEA's). Testing the average impact strength of punches from an amateur boxer and a heavyweight to understand if the padding system could handle 2500 Newtons (amateur) and 5000 Newtons (heavyweight) of force respectively. The initial FEA's showed that the padding system could very well withstand the force of the measured punches, however most of the impact seemed to have been absorbed and dispersed by that first layer [22]. As such another FEA was conducted to test if simply using the Non-Newtonian Padding and Foam could do just as well without the second layer of the omnidirectional structures [23]. Results thus showed that the foam would in fact work just as well if it was instead only utilizing the Non-Newtonian padding.



22. FEA done with 3 layer padding concept



23. FEA done with 2 layers of padding, with a thicker initial Padding layer

Ensuring the feasibility of the padding system concept came way in of computer tested scenarios, but also through physical tests as well. These physical tests were completed through the use of resetable Shock Tabs that would measure impacts with limits at 25 G's of force and 50 G's of force. Sets of two tests were done for both limits, with the differences being which padding was set overtop the tabs - generic padding found in current headgear, and my new padding system.


The physical tests undergone with the Shock tabs and padding system therein allowed for a look into the actual real life representation of what force could be taken from the headgears in question. When testing with the foam padding taken from a market standard boxing helmet, it was shown to hardly resist any impact that was presented against it, realistically providing no protection from the forces recieved. Whereas the padding system concept for the Boxaid concept was showed no affect when being impacted with either set of shock tabs. The padding concept showed to be capable of resisting

shock tabs

26. Resetable Shock Tabs



27. Shock Tabs with Foam Testing



the forces presented to it, and the ability to
come maintain a proper shape afterwards.

Early Model Iteration

To further look towards the validation of the form, beyond simply just utilizing and testing with something as weak as cardboard, tests were done with a more refined model of what the final helmet would be expected to resemble. 3D printed in a sturdier filament, the new model allowed for a better example and feel to the actual helmets possible look, showing details of the protrusions and ear protection.



24. Early CAD Model of Headgear Concept

Although helpful to develop the headform on a rendering software and then allow for computers to create said products, after some deliberation it was found to be far more beneficial if the modeling was done physically out of Automotive clay. This way certain features could be added, removed, and adjusted given the requirements and limitations presented by the headgears design. Ear pieces were also made so as to be removable, to test which would be the best choice over all other design options.



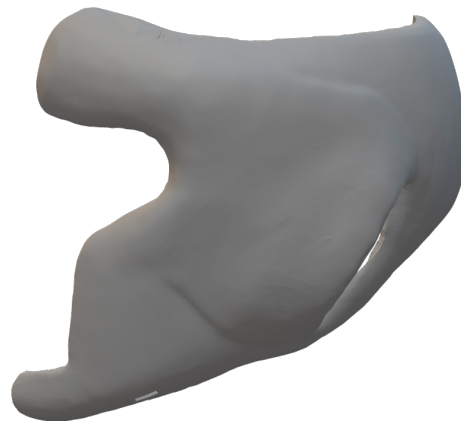
25. Early Automotive Clay Sculpted Headform

Further refinement in the headform was also conducted past the early stages of clay modeling, as the first layer was shown to be too thin on the model and not yet at the desired design. Thus the addition of more clay on the form was done to ensure that it was not only to scale, but also resembling the desired aesthetic in terms of form. The design of the ear piece was also settled upon and added, settling for the same open back concept with the inclusion of the protrusions and the ear protection as being one level. Thus adding to a sleek aesthetic and giving a unique style to the headgear.

After newly refining the clay model, it was scanned to be further cleaned up on CAD software. The scan itself presented new issues and insights into the overall form, some of these being; the smoothness of parts of the headgear, the protrusions and the ear protection not flowing smoothly into each other as originally intended, and certain issues in sizing and cleanliness of parts.



28. Refined Automotive Clay Model



29. 3D Scan of Automotive Clay Revision

Model Refinement

After refining the model digitally, steps were taken to print out the headform to better understand where errors would be in a physical space. Much of what was realized boiled down to the fact that the headform lacked that desired effect of a proper flow overall, and had bumps located at certain intervals of the helmets outer encompassing form. To work with these issues much of the form was sanded to be closer to the final expected finish of the form and also cleaned later to be scanned yet again.

The cleaning of the form past sanding came in way of applying bondo to any cracks in the print or missleveled areas that required more additive steps rather than subtractive ones. Once bondo was applied and hardened, it was yet again sanded to ensure that the form was at that point leveled and without excess pieces or flakes being atop the form.



30. 3D Print of Headgear after some Refinement in CAD Software



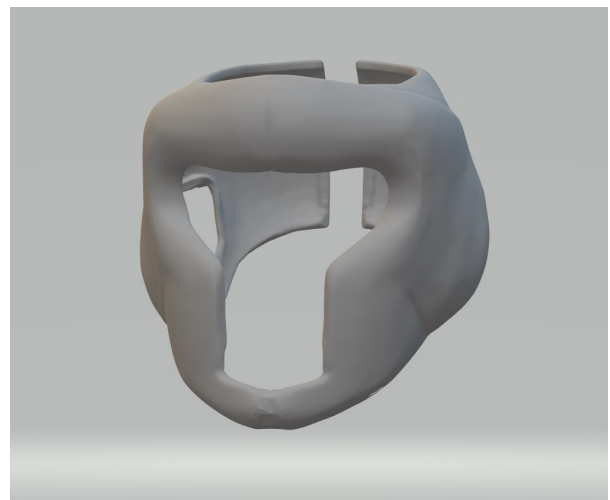
31. Applying and Cleaning Bondo from the Headgear

After the application of bondo and sanding was completed, the model was primed once to see if there were anymore imperfections that were not noticable. Any problems that were then discovered were sanded and yet again applied with bondo. Repeating the process until the form was upto standard for scanning.

Once scanned the model was brought into blender to further smooth and bring out any defining features that were otherwise lacking in the physical model. Once that was completed, the form was mirrored and put together to create a single piece of headgear. To ensure that there was no excess pieces or planes coming out from the inside, a model of the original anthropometric headform was used to act as the reference of what to keep in and out of the model. That was then used as the boolean reference when removing the errors in modeling on the inside of the headfear. Finally being retopologized to fix any geometric complications made when joining the two mirrors manually. This way the whole form could be concise in shape and finish.



32. Primed Model



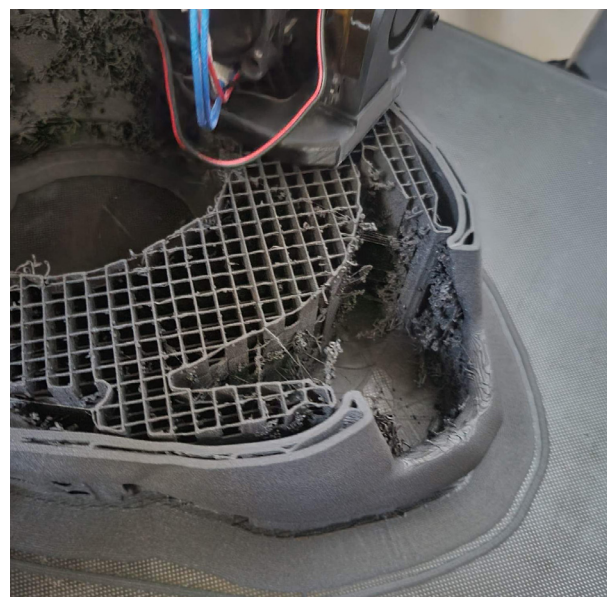
33. Final Model Scan made into full form

After the model was made to a suitable finish it was then set to be printed out of TPU to allow for it to be more flexible and capable of conforming when needed to the fastening system used. Complications arose after the first print had a seam line placed on the front protrusion [34]. Seeing as the seam line had caused the print to appear almost ripped and came across one whole side of the protrusion, it was reprinted to hopefully fix this issue. Other notable issues came from some of the topology still lacking the desired smoothness and flow between the two mirrored halves. Thus the need to remesh the overall form was done yet again till satisfactions were met.


When reprinting the headgear there were minor changes done to the actual settings of the print, the most notable of which being the thickness of the perimeter and the location of the seam line [35]. With a thicker perimeter the headgear would lose a tiny amount of flexibility but ensure that the structure would be stronger overall when printed, and maintain itself well when fastened upon heads. The location change for the seam line was put towards the back of the headgear,



34. Fully TPU Printed Model with Supports and Faulty Seam Line



35. Reprinting of TPU Model with Thicker Perimeters



along the inside and the back of the headgear - where the lacing would reside. This proved to be a better option overall, as the seam line was now almost completely hidden and barely visible to the naked eye.



Final Model

The final Boxaid model utilized all that was gathered through the prototyping phases to culminate in a concise and accurate form of the final design. This accumulated into seamless transitions between the levels and planes of the headgear, a full scale representation of the models form and thickness, and a distinct uniqueness when compared to other existing pieces on the market.

The final model also holds opportunity to be further refined by way of wrapping it fully in cactus leather, to give full range of reference to the desired end product. This would provide context to the look, and

feel of the headgear after being wrapped and sewed with the cactus leather overtop. Showing the location of seam lines, and how that would then on affect the final aesthetic and function of the model.

The final render of the CAD model was made to show the desired look when wrapped in the outer cactus leather material, and when having the inner anti-bacterial/anti-fungal cloth. Making visible the areas seperated by material, and how they are put together.

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