Electronic Unicycle Apparel and Equipment

Maria Edwards

Sports Product Design, University of Oregon

SPD 610, 688 & 689

Vanessa Preisler, Carly Mick, & Rachael Volker

June 13th, 2023

Table of Contents

History

We see the first instances of one wheel motorized vehicles as early as the 1904. These vehicles were classified as a "petrol monocycle" using a wheel that revolved around the rider, combustion engine, and an external wheel for stabilization (Motoruota, 2022). Through the 1900's and early 2000's people came up with many different styles of one-wheel motorized vehicles, some more outrageous than others. The first instance of an EUC (electronic unicycle) that resembles the current design was the Solowheel, developed by Shane Chen in September 2010 and exhibited at the Bike Expo in Las Vegas, Nevada. This is also the first EUC that attained commercial success and was granted a patent in 2012 (The World is Yours. SOLOWHEEL, n.d.).

Currently the electronic unicycle market is dominated by three manufactures; InMotion, Kingsong and Gotway. The EUC's specifications can vary greatly between different models and how much the user wants to spend. They can now come with suspension, and a variety of different top speeds and ranges. As of the time this paper was written the InMotion V13 Challenger has the fastest top speed at 87mph and can have a range of 150miles as seen in the Gotway Monster Pro. (Toll, 2022) (Chang, 2020).

Despite the rise in popularity of the EUC there is currently no one on the market who has designed protective equipment and apparel specific to the needs of electronic unicycling. Users will pull predominantly for motorcycling and motocross equipment but will also take equipment meant for rollerblading, skate boarding and some will also modify their own equipment.

Product Classification

Electronic unicycle, apparel and equipment, men's. The line plan includes; a jacket, pants, gloves and shin and knee guards.

The User

The target users for this line will be men between the ages of 25-50 years old who are intermediate to advanced EUC riders. They will have the ATGATT (All The Gear All The Time) mind set. ATGATT is a common theme in motorcycle safety that has transferred to EUC riding. ATGATT is in direct opposition to "squid" riders, who use little to no safety equipment and create a bad reputation for both motorcycle and EUC riders. Safety for the target user is a top priority and they do not compromise on safety for the sake of having fun or laziness. They use their EUCs for the "last mile connection" to public transport. They are ecologically minded individuals who want to promote a more conscientious choices in the day to day commute. The user may also use the EUC for commuting if the distance is short. The user knows how to have a good time and will use their EUCs for weekend recreation. They enjoy the EUC community and will go out on group and night rides for fun and a sense of community.

A target user profile is Michael; an avid 29-year-old EUC rider from San Francisco. He uses his EUC to commute and is active in the EUC community, going on group and night rides. He spends a lot of time finding the right gear and is frustrated that no one designs equipment and apparel specific for the EUC. He has gone so far as to enlist the help of leather workers and product designers to work on the problems he faces but lacks the support network to get a product to market.

Problem Areas

In an interview with Michael in late September he illustrated the needs of EUC riders using his current products, products he has used and has crashed in and video of EUC crashes. The problem areas that EUC risers face are many, but generally fall into these categories: crash protection, communication, visibility and durability.

Crash protection is predominantly required in the hand, wrist, forearms, knees, with more awkward crashes also involving the shoulders and hips. Most crashes and injuries happen when the EUC stops, but not the rider, launching the user forward and onto their hands and knees. Wrist protection is a big concern as motorcycle gloves do not prevent wrist extension and gloves that do prevent extension in the wrist like skateboarding or rollerblading gloves are not made durable enough for crashes at the speeds experienced on an EUC. The forearms are also scraped along, requiring more durability in that area than seen in motorcycle equipment. Motocross knee braces are used for protection and are a must for EUC usage, Michael says he “never goes without them“. It is beneficial for knee protection to be smooth on the inside to accommodate the wheel and padding.

Also important for safety is communication, for EUC’s to remain legal on the road they need to be able to signal intent. It is also important to be able to signal to other EUC riders during group rides. Hand and hand with this is visibility, seeing and being seen. A lot of EUC riders will install lighting on their equipment to be seen at night and to help with hand signaling. Lighting is important for seeing at night, and fun patterns are a highlight of the night ride experience.

Durability is a must for a protective garment, this paper will be investigating replaceable parts for high wear areas. Ecologically it is better to replace the high wear areas than having to

replace the whole garment. For example, the elastic on knee braces wears out very quickly so making it replaceable will extend the lifetime of the equipment. Crashes will also eat through padding so it is important to have the padding in the high wear areas be replaceable. In a lot of motocross protective equipment padding in the upper body be suspended in fabric, but the fabric is eaten through during a crash, making the garment unusable after a single crash.

The Golden Circle: Why, How, What

Why: I want to inspire a future of inclusivity, empowerment, and sustainability to propel our society into a better future. How: To achieve this, alternative forms of personal transport must become viable and socially accepted. What: My thesis on EUC protective apparel and equipment will create, ecologically minded safety to spread the joy of this sport. In 2010 "Portland, OR, made a commitment… to reduce reliance on personal auto use and increase its bike infrastructure and culture by 2030" (Chang, 2021). This commitment makes Portland, OR a prime place for a developing PEV culture. Imagine, gardens, children playing and couples and friends enjoying a meal outside, the air is fresh, a person on a single wheel glides past to get to the train. This future is possible if we continue to move forward promoting a green future and making cities for people, and not cars. If people are able to safely go out and do what they love, they will be happier and appreciate the world better. How can we create a set of apparel and equipment for male EUC riders that is purpose built for their needs, encourages safe riding through style and, is made with conservation in mind?

User Metrics

The user base for this product will be small, out of 100,000 estimated users as of 2020, Maybe 50,000 will be men with an ATGATT mindset (Winterwheel & Seba, 2020). This

number was derived by the number of EUCs sold and the fact that many EUC users will have more than one vehicle. Not all EUC riders are men, but they are the vast majority and not all have the ATGATT mindset, giving a rough estimate of 50,000 potential consumers for this line. Sebastian Łastowski runs the app EUC.world which tracks mileage and other EUC metrics as well as a place for EUC users to post group rides. This app is not allowed in China, but figure 1 shows the leaderboard stands thus as of 1/14/2020:

Figure 1

By number of tours

Country	Tours
United States of America	3134
France	2793
Poland	1819
Great Britain	814
Czech Republic	713
Austria	634
Sweden	634
Brasil	594
Spain	468
Norway	458

By number of kilometers

#	Country	Kilometers
1	France	50514.892
2	USA	35214.443
3	Poland	24555.111
4	Great Britain	20013.308
5	Austria	8407.026
6	Spain	7202.104
7	Sweden	6894.324
8	Czech Republic	5721.368
9	Italy	4551.090
10	Brasil	4216.332

Note. From *How many of us are there?* (Winterwheel, & Seba, 2020) This set of information will be used later on in the paper when deciding colorways and prints for accent parts in the set of apparel. This set of products will focus on the global market looking at Affluent, people focused cities with vibrant nightlife and EUC communities.

The User's Jobs to Be Done

There is a considerable amount of coordination needed to be successful in this sport. It can take a while for EUC riders to get coordinated on an EUC, thus it is recommended for a

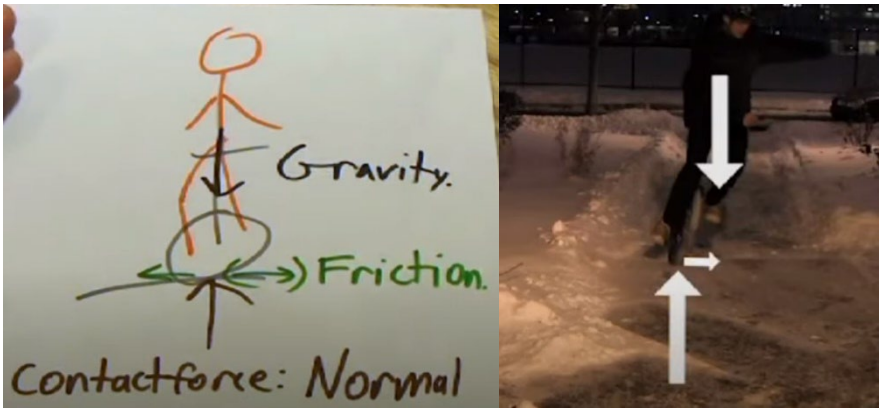
prospective rider to try using a lighter EUC before going on to one of the heavier models. Even though modern EUCs are gyro stabilized, the gyroscopic effect of the wheel turning keeps the wheel stable, making maneuvering around obstacles and pedestrians difficult at lower speeds. After coordination is considered, don't forget to have fun!

In terms of legality, EUCs in a lot of places are in a legal grey area, not having yet been classified in the law. In other places like the UK and now Poland they are not legal on the road and sidewalk, and in other places they are limited in speed, in these instances user discretion is advised (Tolhurst, 2022) (Łastowski, 2022). In both instances, it is going to be important for the EUC user to signal intent, show they are braking and have bright running lights. Currently there are no product solutions for these needs. There is also a gap in what is legal vs what is enforced, as seen by GB being number 4 on the leaderboard. As long as good science is practiced, and users are not harassing law enforcement hopefully EUC using can continue long term.

Biomechanics

Though different sports, the basic physics of riding a unicycle and an EUC are identical. Forces involved in unicycling centrifugal force will keep you upright, as long as there are no other forces applied, the user will continue to be propelled forward. Gravity is also important, it will be influenced by both the user and the weight of the EUC, this force allows the user to influence the direction of the EUC by changing the location of the center of mass. Friction is what actually allows the EUC to accelerate, brake and turn. Counter steering means the user can turn, keep the EUC upright, and therefore stay on. Counter steering involves moving the point of contact in the opposite direction of the desired motion so that the center of mass will be oriented in the desired direction. (MITK12Videos, 2012)

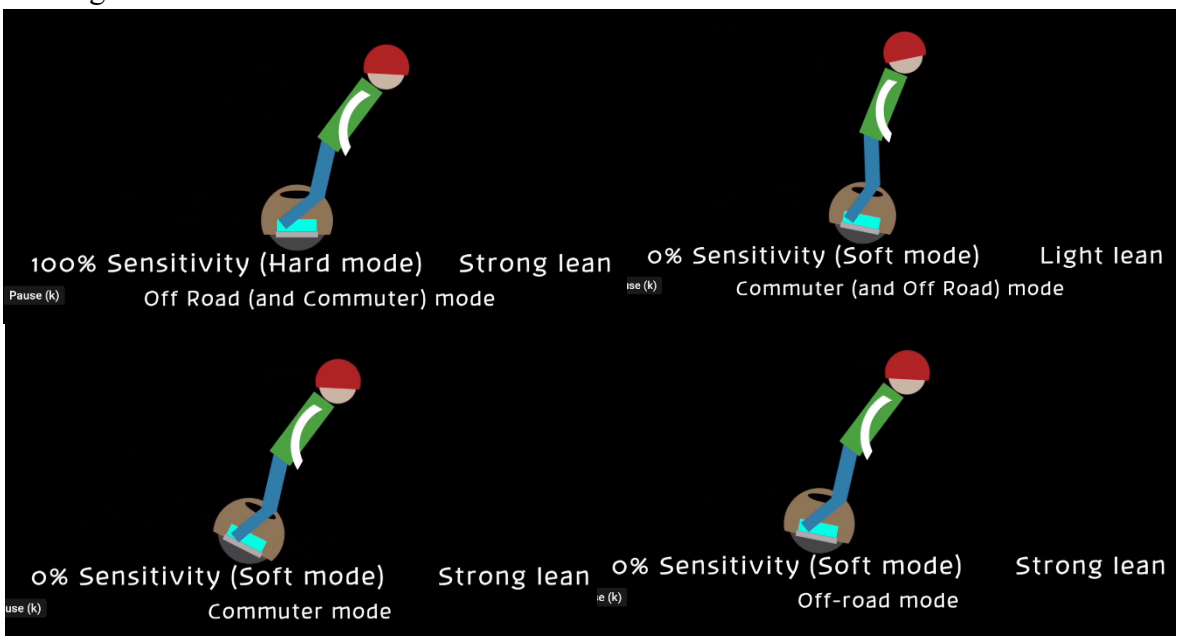
Figure 2



Note. From *The Physics of Unicycling*

The biomechanics of riding an EUC can vary depending on the settings used. The user can change how much leaning forward engages acceleration using the different settings to find the position and acceleration that works for them. With a sensitivity at 100% a light lean will cause the EUC to accelerate slowly and the EUC stays horizontal. Doing a hard lean at these settings will cause the EUC to accelerate faster, however this will be hard on the ankles and will require the user to have good endurance.

Figure 3

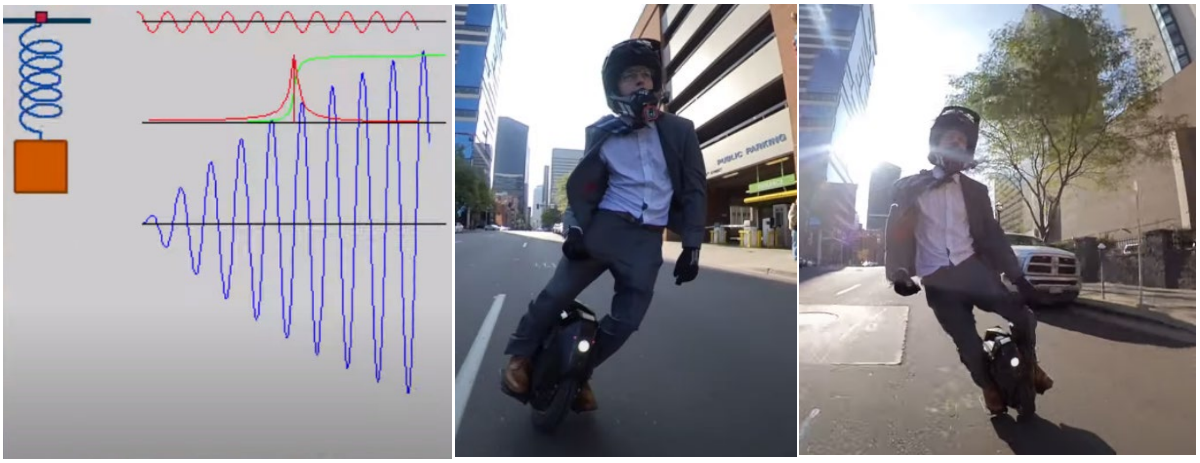


Note. From *EUC ride modes explained*

Sensitivity at 0% will mean that the user does not accelerate as hard, the EUC will lean with the user as they accelerate allowing ankles stay in a relatively normal position. On and off road modes will change how much the EUC will lean before catching you, this changes the angle of the ankles during acceleration (mrelwood_euc, 2022).

What are speed wobbles? They are also called death wobbles or a tank slapper in motorcycling. It is yet to be documented how this phenomenon occurs on an EUC but it often happens at high speeds, over uneven terrain, or even sometimes when the wind blows. The phenomenon causes a resonance within the EUC which will make it wiggle. Unless corrected, the wobble becomes increasingly violent, as shown in figure 4. To prevent this phenomenon an EUC rider will do a sort of slalom motion, shifting their center of mass from side to side. This motion prevents the resonance from occurring at high speeds and during terrane changes.

Figure 4



Braking on an EUC is done by shifting the rider's weight from forwards to backwards. Lighter breaking will slow the user down, hard braking will cause the EUC to start driving backwards. A feature EUC riders will add to their wheels are Power Pads they function as a lever arm and increase the amount of force that the user can apply to the EUC. Braking when going

down hills must be done with caution as the EUC is an unstable equilibrium. If the center of mass falls too far away from the center of rotation for the EUC, the EUC could fall out from under them.

Figure 5

Injury

While performing a sort of baseball slide will occur, the vast majority of single vehicle accidents on an EUC happens when a rider falls forward, and onto their knees and hands. These accidents occur during a loss of balance due to muscle weakness, road obstacles that changes the acceleration of the EUC but not the rider, or during cut off. What is cutoff? An example of it can be seen in figure 6 below. As the battery gets lower it can supply less torque to the motor, this means that an EUC rider must drive less aggressively the longer they are using their EUC. Cut off happens when an EUC rider does not listen the warning sound their wheel makes and

continues to push their EUC, they will be leaning forward when cutoff occurs and will continue forward as the EUC does not.

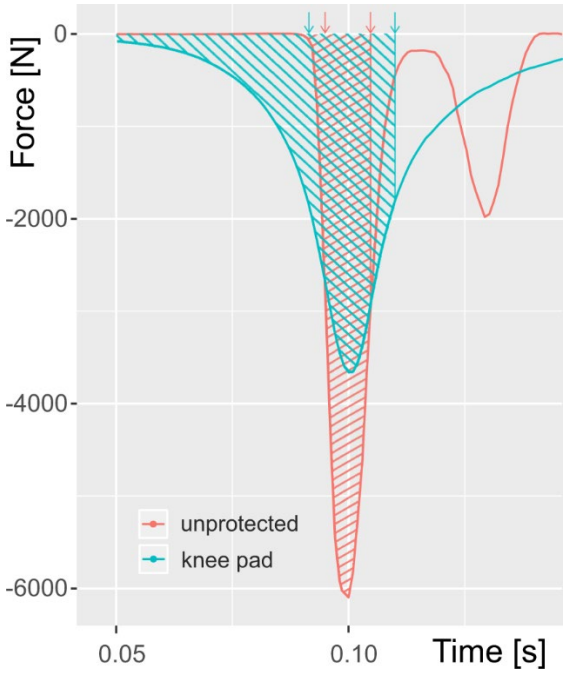
Figure 6

Note. From *VID 20220221 061824*

As the knees are closer to the ground they tend to contact first and then the hands fly forward in an instinctual effort to protect the rest of the body.

Knee injuries without protection can be severe and can include; abrasion, laceration, contusion, sprain, meniscus tear, torn tendon, torn ligament, knee dislocation, fracture (9 Common Knee Injuries from Falling, 2022). Because EUC riders can have these hard knee impacts, knee pads and shin guards are one of the most used forms of EUC protection. Figure 7 shows the difference between impact with protected and unprotected knee. The knee guard used was a hard polyethylene (PE) shell and a soft foam insert. The study found that “The mechanical behavior more closely resembled a spring that temporarily stores energy and consequentially reduces peak forces upon impact”. The study also found that, as the force increased, the effectiveness of the knee guard diminished (Schwarze et al., 2019). This means that further testing of EUC impact protection must be done at the forces experienced in a crash.

Figure 7



Note. From *Force, impulse and energy during falling with and without knee protection*

Different arresting strategies will also influence the peak hand impact force in a forward fall. Subjects in a 2002 studs "were able to volitionally decrease the peak impact force at the wrist by an average of 27% compared with a "natural landing" ($p=0.014$) and 40% compared with a "stiff-arm landing" ($p<0.0005$)… Peak force correlated with the elbow angle at impact, wrist velocity at impact and with pre-EMG triceps activity". Interestingly, compared the natural landing, when the participants were given no instruction, upon being told to reduce their impact force participants were able to lower "the peak force applied to their wrists upon impact with the ground". Stiff arm landings had the highest impact force comparatively. "landing and the minimum-impact landing, the hand impact velocity was reduced by 0.44 m/s and the elbow angle was reduced by 11 degrees… these modifications should lead to a 32% reduction in the peak force applied to the hands." Interestingly, the study also found that no matter the padding

thickness and stiffness used, it “reduced the F1 peak force by approximately 35%” across the board (DeGoede & Ashton-Miller, 2002).

Figure 8

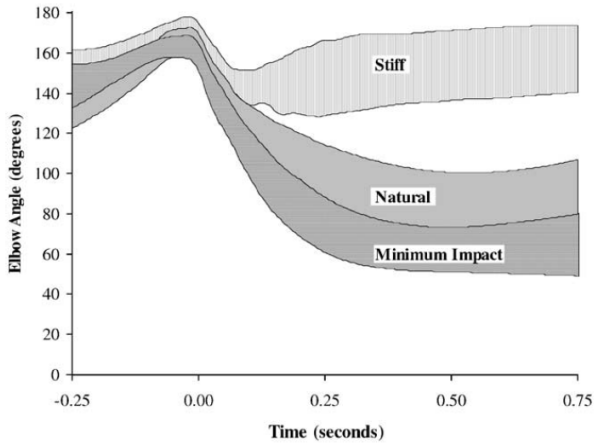
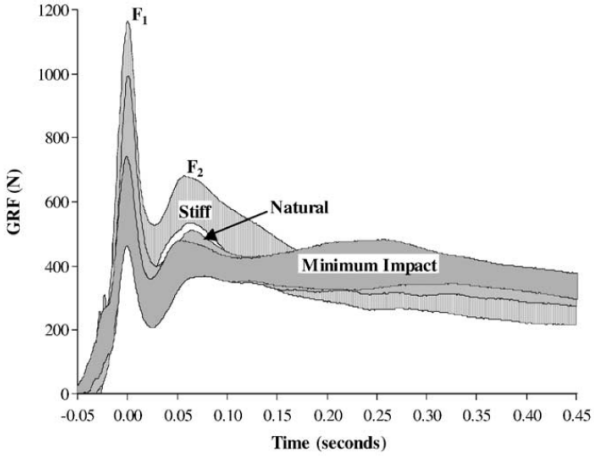


Figure 9

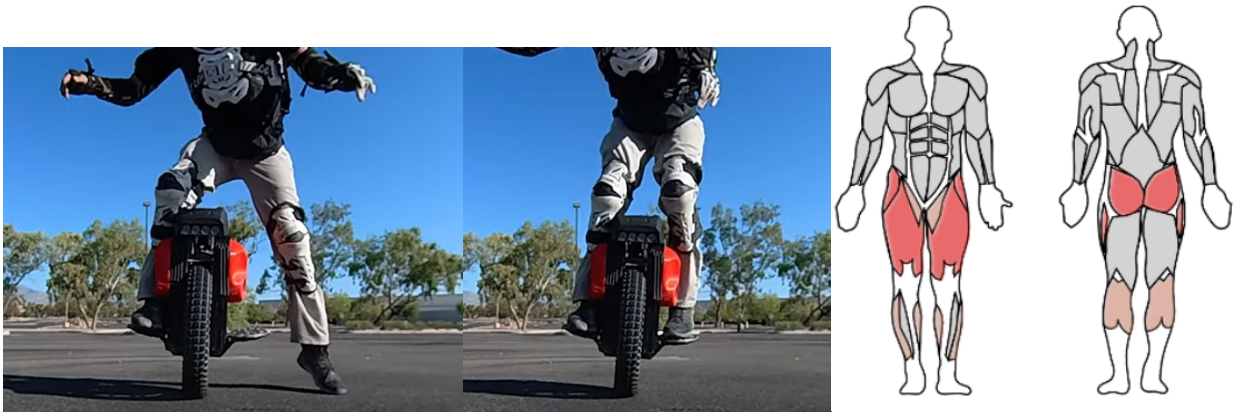


Note. From *Fall arrest strategy affects peak hand impact force in a forward fall*

Physiology

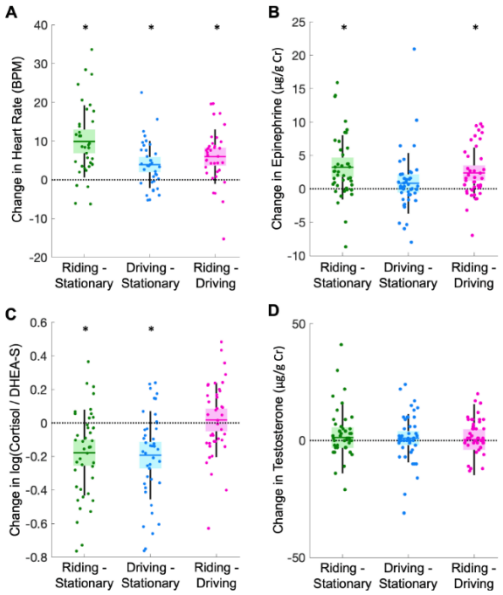
The physiological implications of EUC riding are two fold, they increase slow twitch muscle mass and, extrapolated from motorcycle riding, change the user’s brain chemistry. Takes a month to develop the necessary muscles to stabilize an EUC, and it is important, as weak legs will not be able to stabilize speed wabbles. There are exercises EUC riders can perform to improve performance. The exercise in figure10 illustrates leg ups on EUC and the corresponding muscles used. The primary muscles used are the quadriceps, abductors, and glutes; the auxiliary muscles used are the adductors, calves and abdominals (Exercise Benefits With Proper Form & Technique Side Step-up, n.d). Stretching is also important for mobility in the ankles and knees. Wearing ankle reprotections or high-top shoes during these exercises is recommended to prevent ankle rolls.

Figure 10



Though different sports, motorcycle riding and EUC riding share important factors such as environment, attention to details, and of course thrill that will correlate the chemical changes experienced in both sports. Many EUC riders are also motorcyclists. In a study on motorcyclist Vaughn and his team “observed a diminished N1 and a decrease in posterior relative alpha power, consistent with, respectively, decreased auditory processing of distracters and enhanced visual processing, that together support increased focus in the visual modality.” They also observed MMN, “enhanced pre-attentive sensory monitoring.” The also observed increased heartrate and epinephrine levels “during riding suggest a heightened state of arousal.” This evidence showed support for another hypothesis on the “interaction between arousal and cognitive processing”. Lastly they observed a decrease in “cortisol and cortisol to DHEA-S ratio during riding provide data consistent with the self-reported stress reduction that accompanies the riding experience. Similarly, and in various stress reduction activities, cortisol levels were found to be decreased” (Vaughn et al., 2021)

Figure 11

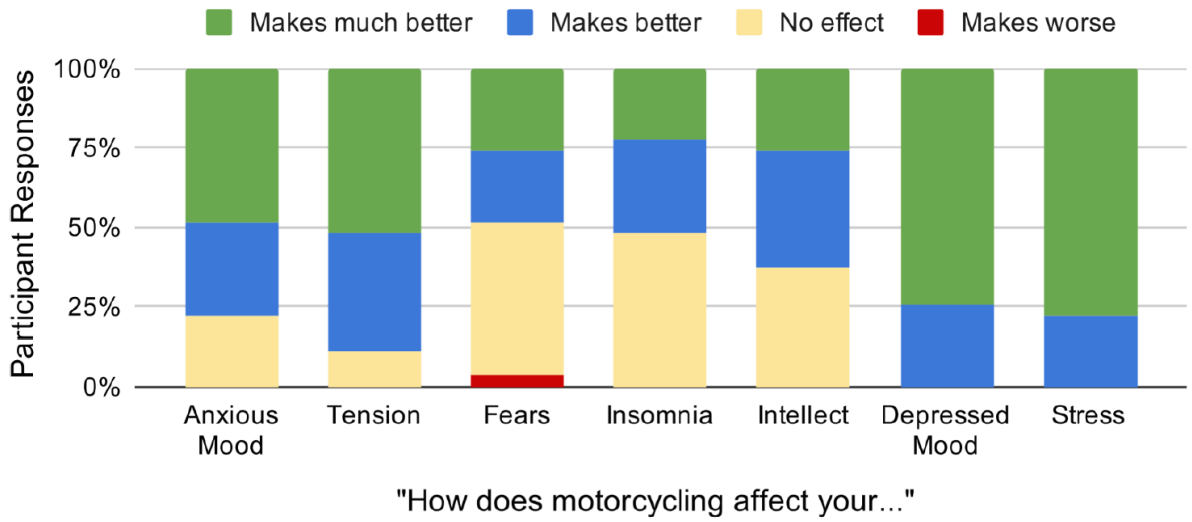


Note. From *Modulation of attention and stress with arousal: The mental and physical effects of riding a motorcycle*

Phycology

Psychologically what do these changes in hormones mean for a user? “Riding a motorcycle decreased hormonal biomarkers of stress by 25%”. Comparatively, “sensory focus was enhanced while riding a motorcycle”. Lastly, brain activity shows an increased alertness “similar to drinking a cup of coffee” (Harley-Davidson Motor Company, 2021). Participants in the study Vaughn had conducted in 2021 self-reported many psychological benefits to motorcycling. Again though these are different sports, Motorcycling and EUC riding attract similar people and have similar environmental stresses and the need to respond calmly to dangerous situations.

Figure 12



Note. From *Modulation of attention and stress with arousal: The mental and physical effects of riding a motorcycle*

People who are attracted to the EUC are varied, from adrenaline junkies to the environmentally conscientious. Currently they are innovators and early adopters, with money to spend on a new hobby and the time to learn a new form of transportation and what gear works out for them. “EUC’s are tons of fun! It’s like mini jets have been put on your feet and you can hover or fly where you like and when you like, the ultimate “Freedom of transport” (Chan, 2020). They are adventurous souls and people looking for community, users go together on group rides, night rides, they make friends with people they would not otherwise and it is all because of this funky little form of transport. “We find that the world of EUC riders is a youthful, optimistic community with an amazingly positive and supporting vibe. We’ve made friends for life thanks to EUC’s!” (*The Pros and cons of electric unicycles,* 2022)

Riding mentality is all about being aware of road conditions, recognizing threats, opening car doors, thinking no one sees you and everyone is out to get you. Having good emergency braking distance, staying left or right in lane to avoid accidents. Riders must have the “mentality

and confidence to ride something out" (Go George Go!!, 2021). Users do this by practicing their skills to increase confidence. Just like with other high intensity sports, "panicking is the worst thing you can do in any type of dangerous situation" (Go George Go!!, 2021).

The Environment

Surface conditions will include roads and paths found in city and urban roads and trails; Asphalt, pavement, some cobblestone, gravel, and dirt. The cities focused on in this paper are all in temperate, hospitable environments with low to moderate rainfall. The temperature range will fall between 50-80F with a humidity of 80-40%. Many EUCs are not waterproof, so waterproofing will be considered, though not a high priority for this project. As an intrinsic part of the environment users will be encountering cars, motorcycles, pedestrians, bicycles, scooters and other EV users. As night rides are so popular, nighttime lighting conditions will also be taken into consideration.

Product Rules

There are no set rules for EUC equipment, however this gear will need to keep the user safe in case of an accident and help the rider with signaling and visibility. This set of products will aim to fall within the guidelines of the "Conformité Européenne" (CE) which regulates safety and gives rating to different types of equipment. The aim will be a CE rating of AA meaning it provides abrasion resistance for 43 mph and at a minimum of level 1 protection (Protective motorcycle gear: Fabrics explained, 2021). CE guidelines will be used during testing of the product to make sure the set of equipment meets these ratings. EN 13595-1 and EN 17092-3:2020 state the guidelines for testing and garment requirements to meet AA standards. These

guidelines will be subject to change after March 2023, so while the requirements will change their testing methods can still be used as a guideline and reference for testing. The guidelines are split into 4 parts, the first section regards an overall examination of the apparel, while 2-4 involve testing for “impact abrasion’, ‘seam burst strength’ and ‘impact cut” testing (En 13595-1).

Competitor Products

Figure 13: Popular Jackets for EUC Riding SWOT Analysis

Product	Price	Strengths	Weaknesses	Opportunities	Threats
HWK Textile Motorcycle Jacket	$60	Reissa waterproof membrane keeps rider dry in the rain. Reflective accents keeps rider seen at night. Removable thermal liner makes jacket usable in cold or warm.	CE A rating means it will only be suitable for EUC riders going under 28mph.	Zoning Specific to EUC riding would make equipment more effective.	Product is from a small brand, and sold alongside many similar products on amazon.
Alpinestars Bionic Tech V2	$300	Porous structures in padding provide ventilation. Adjustment straps keep padding tight to the user Viscoelastic paddings allows for mobility and impact protection as needed.	Mesh between armor plates is prone to shredding.	Zoning and substrate specific to EUC riding would make it more effective.	Alpinestars has made no attempts to get into the EUC market.
Armored Reflective Jacket	$250	Reflective fabric keeps rider safe at night Internal padding is replaceable. Kevlar® fabric inner lining keeps skin safe in accidents	Interior material is abrasion resistant, in an accident the outer materials would be shredded CE A rating means it will only be suitable for EUC riders going under 28mph.	Changing outer layer would make garment more effective	For a garment made specifically for micro mobility, an already small community, they have failed to meet market popularity.

Figure 14: Popular Pants for EUC Riding SWOT Analysis

Product	Price	Strengths	Weaknesses	Opportunities	Threats
Armored Casual	$210	Made with Kevlar liner to protect the skin. Eco conscientious replaceable knee padding. Overlock stitch for durability.	Padding moves around in fabric sockets in an accident. Outer material will be shredded in an accident	One of the only players on the micro mobility market	Viewership has remained small High cost for an A rated pant
VNfox VES6	$60	Denim for a comfortable, fashionable look. Detachable hip and knee pads for protection. Windproof for comfortability during ride.	Padding moves around in fabric sockets in an accident. Outer material will be shredded in an accident Base material is not CE certified and is flimsy	Lower cost makes it appealing for people starting.	Padding is not adjustable
Alpinestars Ramjet Air Pants	$250	Vents on the thighs direct air to cool user. Accordion stretch inserts on back and knees for mobility. Detachable hip and knee pads for protection.	Softer padding in knees to be accompanied with knee guards would increase comfort.	Alpinestars has a good reputation.	In the same price point as a lot of other motorcycle brands

Figure 15: Popular gloves for EUC Riding SWOT Analysis

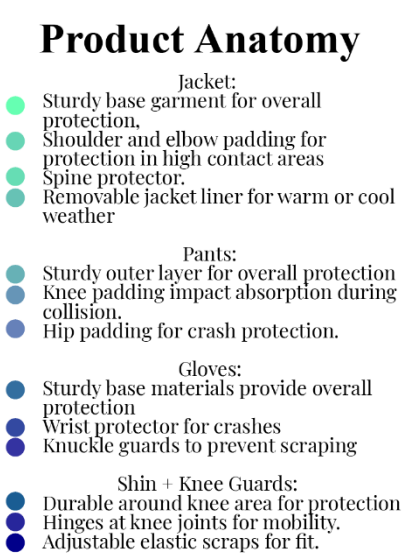
Product	Price	Strengths	Weaknesses	Opportunities	Threats
Hillbilly Full Finger Gloves	$44	Goatskin and double stitching provides durability. Wrist guard provides wrist protection in a crash. Full fingers allows for full hand protection.	Glove does not aid is signaling Glove provides no knuckle protection	One of the few gloves designed for the micro mobility market	The market for micro mobility is small, and this product can only be found on UK websites
1Protect All-Weather Gloves	$80	Waterproof synthetic leather protects hands from the wet. Padding in palm provides cushioning in crash. Puck in wrist is replaceable	Glove does not provide full wrist protection, just abrasion resistance	One of the few gloves designed for the micro mobility market	Poor viewership, not known in the market

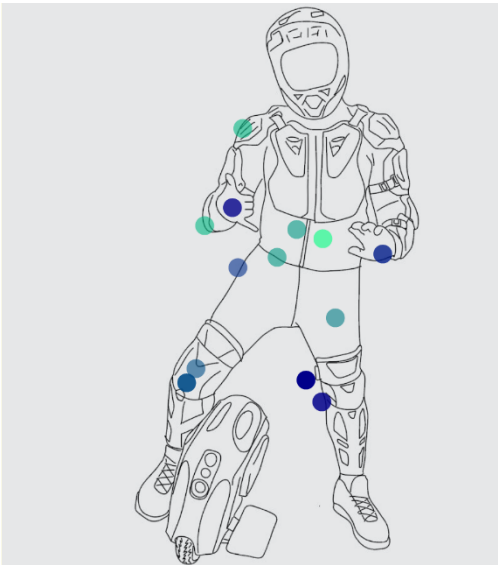
		for conservation.			
Knox Handroid MK4 Gloves	$300	Exoskeleton finger spines which cover the tops of the fingers for impact protection. Boa lacing system ensures comfortable fit. Padding in wrist provides scaphoid protection.	Does not provide wrist protection	Totes a unique finger protection system and is one of the few gloves tightened by a boa lacing system.	High price point

Figure 16: Popular Knee and Shin Guards for EUC Riding SWOT Analysis

Product:	Price	Strengths	Weaknesses	Opportunities	Threats
Leatt Knee Brace C-Frame Pro Carbon	$457	Multiple hinges allow for natural movement of knee. Carbon fiber keeps the knee braces lightweight and durable. Straps allow for adjustable fit.	Elastic wears quickly and is not replaceable	Leatt has cornered the market on knee and shin guards. They could make fantastic equipment for EUC users if they diverted resources to it	High price point Leatt has many knee and shin guards.
Leatt Knee & Shin Guard Dual Axis	$100	Hinge allows for optimal knee movement. Straps allow for adjustable fit. Inner metal kneecap protects against abrasion.	Knee wear pads are not replaceable		
Leatt Knee & Shin Guard 3DF Hybrid EXT	$121	Soft and hard-shell protection allows for protection and comfort. Knit base allows for breathability. MoistureCool and AirMesh helps fight odors.	Knit materials snag and abrade easily		
Fly Racing 5 Pivot	$96	Singe hinge allows for knee movement	Knee cap section floats, providing less impact protection. Fabric around knee cap area allows protection to move around.	Adding armored outer layer will increase performance.	Little known in the EUC market.
Alien Rides Carbon Fiber Knee Pads	$210	Carbon fiber is light wright and very abrasion resistant.	There is no hinge in this product. There is little padding within.	Further development and marketing can make this a great product for EUC.	Little known in the community despite being for E rides.

Product Anatomy





Jackets used by electronic unicyclists are primarily from motorcycling and motocross. Motorcycle jackets are what most closely resembles what will be made in this thesis. They are comprised of a sturdy base garment for overall protection. The jacket will also have various zippers installed, some for pockets and others to open ventilation areas. They will also have shoulder and elbow padding for impact absorption and protection. They also have a spine protector, these can be removable, so the spine protector can be updated as needed (Padway, 2021). In many motorcycle jacket models they also come with a removable liner that can be zipped in and out of the garment to make it more versatile.

Jackets for EUC riders will need to differ in a few ways. In motorcycle accidents the rider will frequently tip sideways, making the shoulder and elbow some of the first places to contact. By contrast, EUC riders predominantly fall forward, the affected areas in this case will be the wrist, forearms, and chest. It would also be prudent for there to be lighting and reflective paneling on the jacket as night rides are so popular. Many serious EUC riders will also have apps tracking their EUC metrics and speed, this means that there will need to be a battery installed on the jacket to keep one's phone charged as well as a mount for the phone (Edwards & Arnaldo, 2022).

Like the jacket, the pants will also be similar to ones used in motorcycling. They are primarily comprised of a sturdy outer layer for overall protection. They will frequently have knee padding and may also have hip padding (Padway, 2022). In styles used in racing, they will also have skid blocks attached to the outside of the knee area with velcro for replaceability.

In the case of EUC riders, they mostly use separate knee armor at the front of the knee for impact absorption abrasion resistance. For this reason, the EUC riders' pants will primarily have padding within the front part of the knee. In more serious crashes they can also roll onto their hip so an area for abrasion resistance and padding will also be in the hip. Knee padding in a motorcycle pants is lower than what will be needed for EUC riders. In a sitting position as seen in motorcycling, knees are bent and the knee padding moves up to center in front of the knee. EUC riders are standing, with knees only slightly bent to aid in mobility, so proportionally the knee height will need to be adjusted (Edwards & Arnaldo, 2022).

Motorcycle gloves are comprised of an overall sturdy base material. They will have also frequently have finger and knuckle guards to prevent scraping; comprised of a few different sturdy plastics or carbon fiber. The pinky is also regularly sewn somewhat attached to the ring finger (Padway, 2022). Gloves for motorcycles will also come with a variety of insulation types or none at all depending on if it is a summer or winter glove.

EUC gloves will need to have the added bonus of having a wrist and palm guard, as they can fall heavy onto their wrists in an accident. They will also need to have reflective paneling installed for aided signaling, or better yet, an actual signal light imbedded into the glove. It would also be prudent to have a reflector mounted to the top of the hand for rear visibility. EUC riders have the unique benefit of being able to use their hands during their rides, they can hold

and carry things as well as use their cellphones for navigation and speedometer so the fingers of the glove will need to be touchscreen sensitive and dexterous (Edwards & Arnaldo, 2022).

Knee braces used for EUC riding predominantly come out of dirt biking and motocross. Some riders will use knee pads designed for rollerblading and skateboarding though some with less overall protection and durability. Motocross knee and shin braces are comprised of a durable area for knee protection, hinges along the inner and outer knee for mobility, and adjustable elastic straps for fit (Padway, 2022).

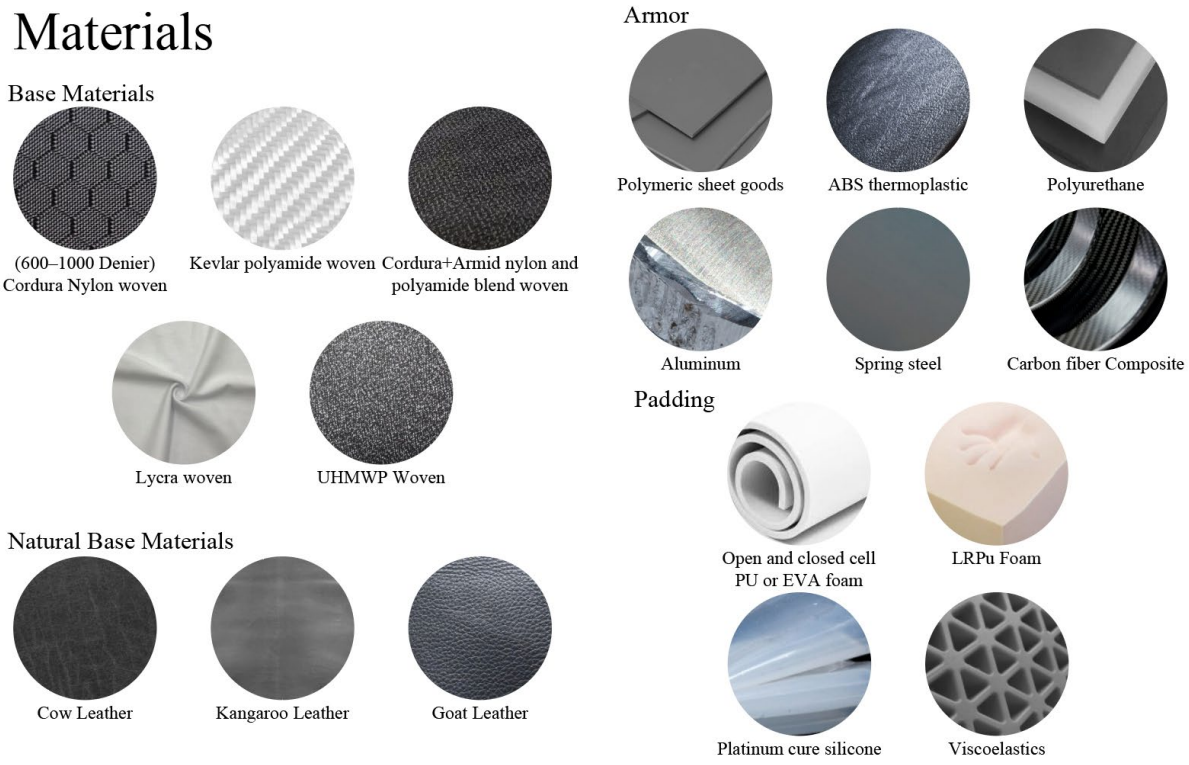
Knee braces are one of the most important forms of protection for EUC riders. The front of the knee is one of the first places to contact the ground. These knee braces will need to be incredibly strong, and because of the frequency and severity of wear, will need replaceable skid protection at the front of the knee. It will also be ideal for the elastic attaching the knee brace to be replaceable, as that is a high wear area. The overall profile of the knee and shin guard will need to be sleek, as the lower leg is frequently wedged between pillars built onto the sides of the EUC (Edwards & Arnaldo, 2022).

Current Materials

Base materials in apparel and much of the equipment in motorcycling consists of; High density (600–1000 Denier) Cordura Nylon woven, Kevlar polyamide woven, Cordura+Armid a nylon and polyamide blend woven, lycra woven, and UHMWP (Ultra-high-molecular-weight polyethylene) Woven (Protective motorcycle gear: Fabrics explained, 2021). Naturally derived base materials include non-woven leathers from cow, kangaroo or goat. Padding materials can be made of a variety of different materials including: open and closed cell PU or EVA foam, low-resistance polyurethane foam (LRPu), platinum cure silicone, and viscoelastics (Canada's

Motorcycle, 2015). Armors can be composed of polymeric sheet goods and woven, composite layups thereof, ABS thermoplastic, polyurethane, aluminum, spring steel, and resin impregnated carbon fiber woven (Parrotte, 2022). A variety of different finishes can be applied to these materials such DWR treatment for waterproofing, high vis applications for increased visibility, waterproof seam tape for a sealed finish, or velcro appliques for removable parts.

Figure 17

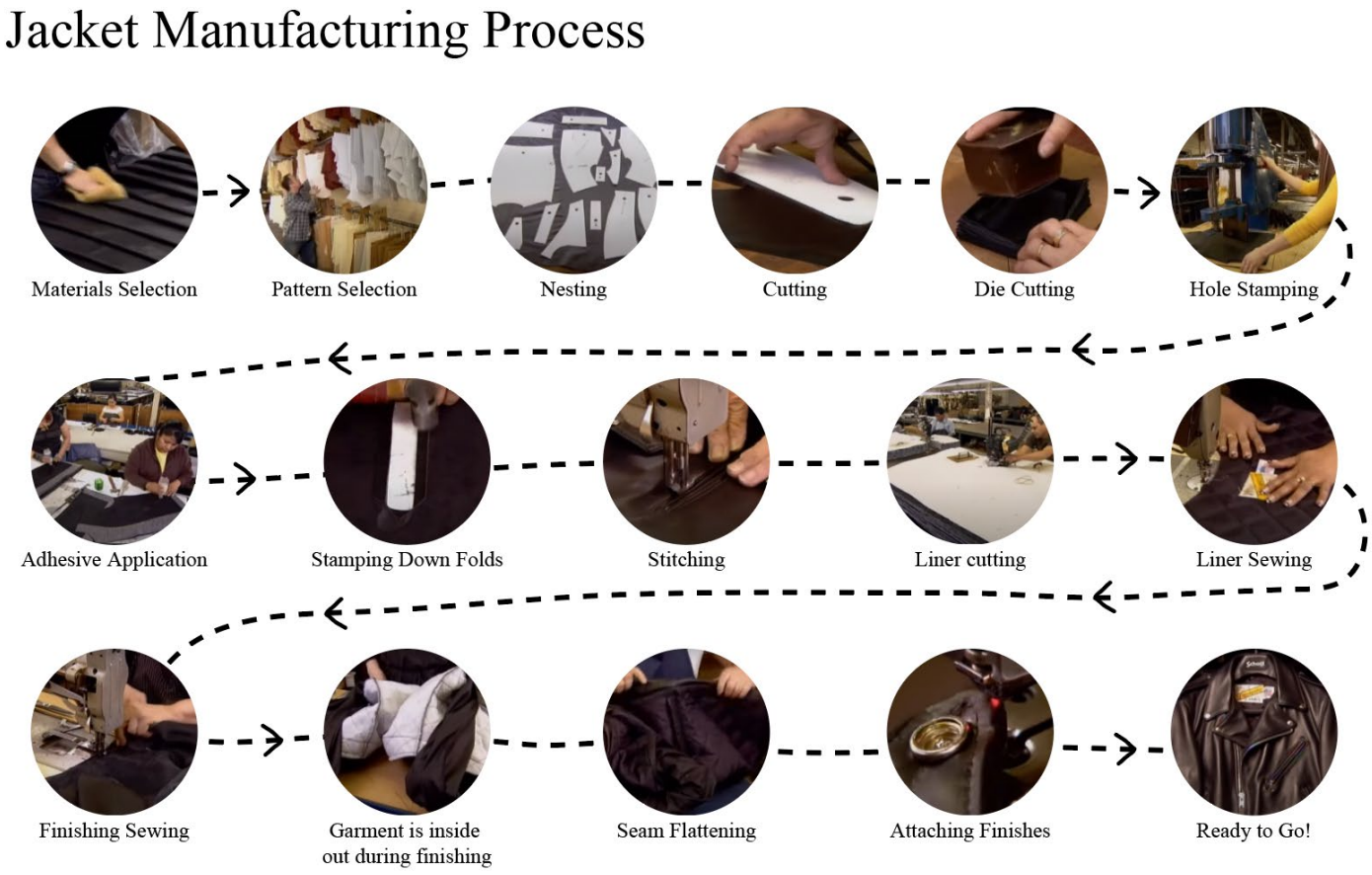


Current Manufacturing

Manufacturing gloves, jackets, and pants primarily involves cut and sew. Dye cutting is used for patterns that apply to multiple sizes and styles like pockets, tabs and decorations. Contact adhesive is used to primarily bond leathers before topstitching (How It's Made - Motorcycle Jackets, 2012). Padding is made through casting in a mold. Armor is either molded, thermoformed, or injection molded. Applying armor and padding can involve heat bonding,

contact adhesive and top stitching. Metal and carbon fiber components on knee braces and other armor can be milled or molded. Metal components can be stamped. Rivets or fasteners are also applied to integrate different hard good parts (Leighton & Silvestro, 1984). Special manufacturing methods can include friction welding for waterproof gloves, laser cutting for ventilation, stamped finishes like grommets and snaps.

Figure 18



Relevant Patents

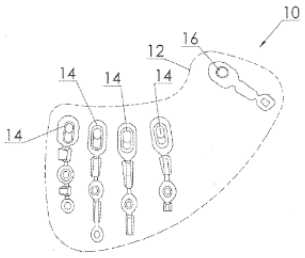


FIGURE 1

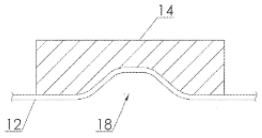
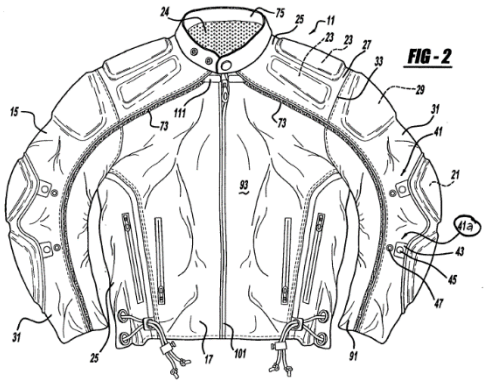
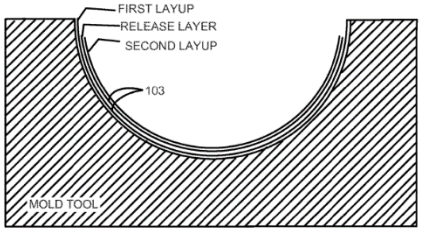


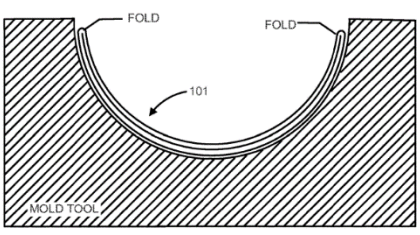
FIGURE 2

Pub. No.: US 2016/0174641 A1 is a patent that was published but abandoned by Leatt in 2016. It is a manufacturing method patent, claim one states: “Protective wear such as a glove comprises a textile fabric substrate with elements of a synthetic plastics material that hardens on being subjected to impact, injection molded onto (51) Int. Cl. the fabric” (Leatt et al., 2016). As long as injection molding is not used in the manufacturing process of subsequent products, they will not be in violation of this patent.



Pub. No.: US 2005/0235392 A1 is an example of an active design patent. It was granted to ROBISON'S Inc Harley Davidson Motor Co Group LLC in 2005. It stipulates that “A garment comprising: a substantially vertical main zipper located at a front torso region; at least one supplemental zipper located in a front and upper torso region, the supplemental zipper being angled between about 30°-150° relative to the vertical main zipper; a collar, upper ends of the main and supplemental zippers being located adjacent the collar” (Bay, 2005). This patent is in regard to a hybrid ventilated garment, but the wording of the patent means that other jackets will be in violation if they have the zipper arrangement mentioned in the patent.





Patent No : US 10 , 189 , 209 B2 was granted in 2019 and is another active manufacturing patent involving “curing [a 3 part] composite layup; cutting a hole into the cured composite layup up to the release liner; inflating the composite layup through said hole; applying a coating into the

inflated layup through said hole" (Downs et al., 2019). This method of manufacturing will not be used in the future prototypes of this project.

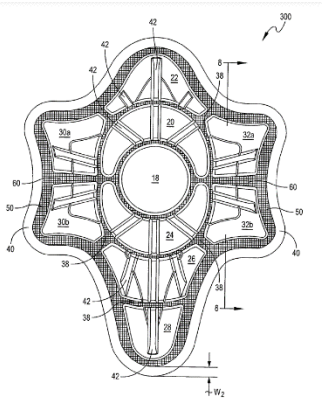
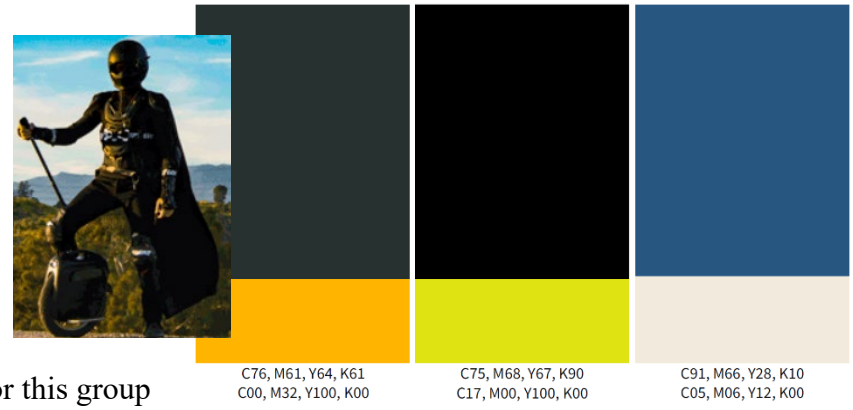


FIG. 7

Patent No: US 9 , 782 , 662 B2 is an active patent that was accepted in 2017 and is another materials and manufacturing patent for flexible cushioning pads. The cushioning pad is comprised of layers of variable width polymeric film. The upper and power layers are continuous, the upper layer is at least partially bonded to the continuous lower layer. The cushioning region is larger than the adjacent first channel. There are channels and groves in the padding for flexibility (Wyner et al., 2017). The patent will not be violated if one of the layers is not a polymeric film and instead was sheet metal or woven like carbon fiber.

Colors, Graphics and Logos



The current color trend for EUC riders is all black. There can be a few areas of high vis material that is a grey color. RGB lights are very popular for night visibility and can be programed to the preference of the rider. Future color trends for this group are inspired by the WGSN forecasts. Dark springs with accent Nectar was pulled from S/S 22: Euphoric forecast "Energising the mind, body and soul through the power of design"(Euphoric). Men's Forecast S/S 24: Creative Confidence, provided Black with accent Cyber Lime, "main character energy" through a "balance of brights against peppy mid-tones" (Paget, 2022). Active Colour Forecast S/S 23 contained a base color of Atlantic Blue with accent Unbleached Cotton

"bright mid-tones offer a simultaneously uplifting and comforting palette with a slightly vintage feel" (Kostiak, 2021).

The vast majority of gear worn by EUC riders does not use graphics, sticking with the black base. Different graphic patterns can help EUC riders maintain their individuality as this project explores a unanimous silhouette to best meet their performance needs. Graphics can include Punk Pop and metaverse graphics as seen in Project & Agenda A/W 22/23: Men's Prints & Graphics (Krag, 2022). Key Prints & Graphics: Women's & Men's Active A/W 23/24 included Techno Swamp, inspired by living organisms in the swamp and sea and Art-letes "expressive patterns and motifs with modular geometry and a collage aesthetic, inspired by the Dada art movement of the early 20th century" (Browning, 2022). Lastly, WGSN article Key Prints & Graphics: Women's & Men's Active S/S 24 explores "Tropadelic" the concept of the relationship between technology and nature, using electric bright natural themes set on dark backgrounds (Browning, 2022).

Branding as seen in EUC riding is generally very limited and discreet, the two brands that both stand out are Alpinestars and Leatt, these brands will have logos places in the upper middle or side of their products is a contrasting color. Branding and logo trends applicable to EUC riding include Key Trend 2022: #RacerRevival and Core Item Update: Men's Active

Apparel A/W 22/23. #RacerRevival is especially applicable as it revolves around retro nostalgia seen in motorcycle racing equipment and gives it a pop cultural lens the trend has been adopted by “Diesel, Balmain, Dior and Chanel”. The feeling embraces “freedom and radical sports with a punch of youth rebellion” Logos seen in this trend are bold vintage style as seen in the motocross jacket aesthetic (Giustino, 2022). Core Item Update: Men’s Active Apparel A/W 22/23 aligns well with the #RacerRevival and adds logo placement on side seams and in bold offbeat areas (Saygi, 2021).

User Research Methods

User research will be conducted in a threefold process, through survey, informal interview, and shadowing. Users will be contacted through Facebook groups, and on the subreddit r/ElectricUnicycle and on the Electric Unicycle Forum with a survey written on google forms. The data from this survey will be collected and analyzed no later than the 5th of December. The survey includes an optional question for willingness to interview. Shadowing will also occur through attending one of the many Friday Night Rides located in Portland OR. Contacts will be gathered, and informal interviews will occur prior to December 5th and get integrated into the research findings. The below questions are found in the survey and are example questions for the interviews. Figure 19 shows the demographics of the 31 participating users, how they use their EUCs, what their top 10 priorities are for each product group, and key takeaways from the individual interviews.

How long have you been riding an EUC?

What is your gender?

What type of EUC riding do you do? Select all that apply.

- Last mile commuting
- Commuting directly

- Urban riding
- City riding
- Night riding
- Group riding
- Off road
- Jumps, and terrain parks
- Riding during cold days, 35F/1C
- Riding in the rain
- Riding during hot days, 95F/35C

What gear do you currently use? Please list all including EUC.

Have you been in an accident, if so, where were you injured or where was your gear distressed?

What do you look for when purchasing protective knee and or shin guards?

What do you look for when purchasing gloves for EUC?

What do you look for when purchasing a jacket for EUC?

What do you look for when purchasing pants for EUC?

What do you carry on your person while riding an EUC?

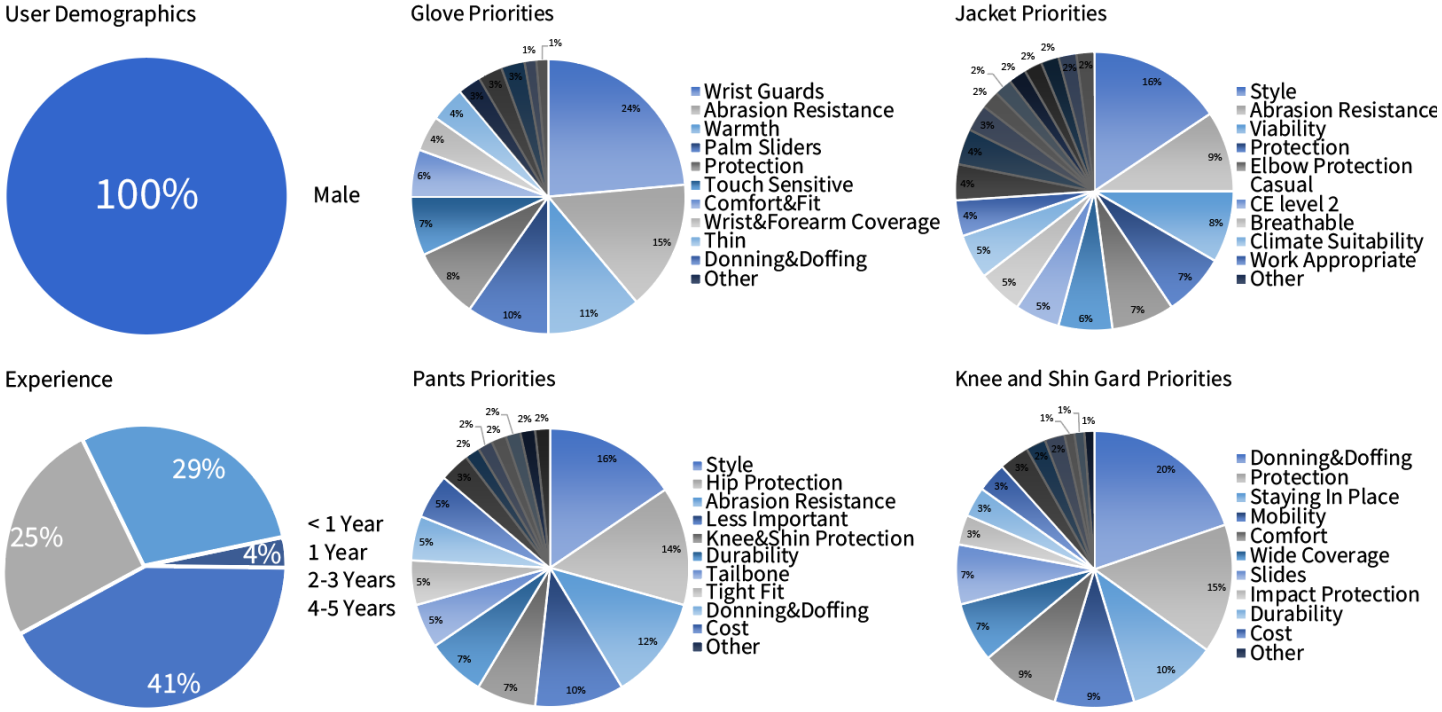
Is there anything that your gear is not doing currently that you wish it did?

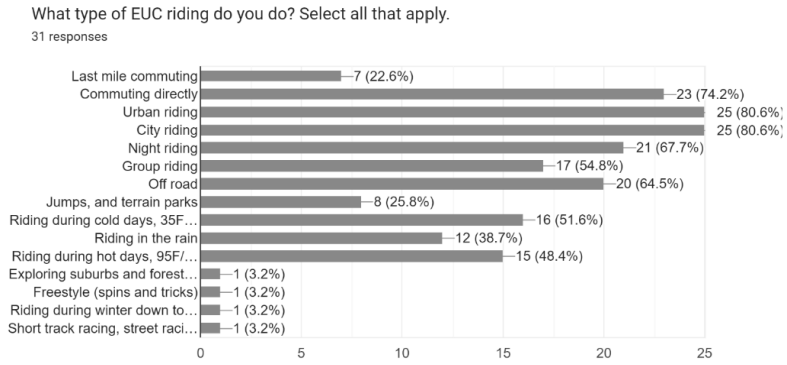
Where would you prefer lighting be placed for signaling intent and visibility at night?

If money was no object what would your ideal ensemble for EUC riding look like?

If you are interested in product testing (for those in Washington to N California) or giving feedback later on in the design process please write your email here.

Figure 19





Individual interview takeaways:

- ATGATT really restricts mobility, wants protection that does not hamper mobility. The joy or mobility is centered in the sport.
- Uses side pockets a lot, likes a lot of pockets
- Left arm has rotating phone holder
- With lazy rolling jackets, Kevlar starts to show and the padding sifts because it is surrounded by fabric
- Lighting at wrist is important for viability and signaling
- Gloves need to be touch sensitive
- We do not want to look like motorcyclists

Testing Protocol

The majority of the testing regarding competitor product will use the user's owned products for specific detailed analysis on individual product. If product needs to be provided the products will be: Lazy Rollings Armored Reflective Jacket for $265.00, VNFox Men's Motorcycle Riding Pants for $59.88, Hillbilly Full Finger Gloves for $29.99 and Leatt Brace Dual Axis Pivoting Knee and Shin Guards for $99.99.

Since we will not be taking apart products to test for durability and impact protection, material swatches will be used in their place. Tested padding materials will be: open and closed cell PU foam, high and low density silicone foams, high and low density silicone, memory foam, and D30. Base materials for testing will be: kangaroo leather, goat leather, 1000 and 500 denier Cordura nylon, carbon fiber, and Dyneema composite UHMWPE.

Movement testing will be conducting in Seattle, WA, Portland, OR, and San Francisco, CA. The test will be short and as such can be conducted at group meets, when a final product is being narrowed down, it can be conducted in the Nucleus lab. EUC riders will wear their own gear during testing, if some gear is not available it will be provided and be one of the above mentioned products. In summary, riders will perform a set of tasks and movements associated with the sport. This set of movements will be identified during shadowing. The gear

in use will be documented. Perceived effort will be documented, short answer questions and a 1-10 scale will be used for different elements the same questions will be used when testing the produced products to compare and contrast these elements. Material tension will be observed and noted, this will be used to ensure there is enough ease in the garment and make sure there are no areas of high tension. These tests will be used to research what elements of the design work, and which do not, to narrow down on the best mechanisms and patterns.

Step	Step Details	Method of Documentation	Time 7 min
Paperwork	- Consent Form - First name, years in sport, age, EUC used - Jacket, pants, gloves and Shin/knee Guards	Form Questionnaire	3min
Movement test Jacket	- Movement set and materials observation - Perceived effort	Form Questionnaire	2min
Movement test Pants and S/K guards	- Movement set and materials observation - Perceived effort	Form Questionnaire	2min

Visibility testing can occur during the same sessions as movement testing. Like movement testing, these tests can be conducted at group meets and in the lab with the user's own gear. The gear in use and mods made will be documented. Satisfaction rating will be noted using a 1-10 scale and a diagram will be used to illustrate where lighting would be preferred. The percentage of visibility will be documented and a photo will be used to see if the lit silhouette looks like a person. This set of tests can be used early in the design process to figure out what lighting systems would work best and how they are perceived by the user to ensure that the visibility patches have the desired effect while also aligning with the user's tests.

Step	Step Details	Method of Documentation	Time 6min
Paperwork	- Consent Form - First name, years in sport, age, EUC used	Form Questionnaire	4min

	- Jacket, pants, gloves and Shin/knee Guards - Document Mods		
Visibility measurement	- percent visibility is observed and photographed - perception at distance is noted	Form Photography	2min

Impact testing will be conducted in Portland or Beaverton, OR. This will be a lab test on swatches of padding. The padding with the least bounce, the most force absorption, will be the one used, or a variation will be used, for the final product.

Step	**Step Details**	**Method of Documentation**	**Time 21min**
Setup and Paperwork	- Swatch Documentation - Test setup	Form	4min
Impact Test	- record bounce. - Repeat 5-10x	Form	12min
Take down	- Remove materials from testing area		2min
Graphing	- visually represent data	Graph	3min

Base materials swatch testing will be conducted in Portland, OR at University of Oregon's Nucleus lab. Base material will be abraded with sandpaper and will be timed till disintegration. Results will be graphed and compared. This set of tests will be used to determine the best material or material layups to be used in the final product.

Step	**Step Details**	**Method of Documentation**	**Time 56min**
Abrasion test setup and Paperwork	- Swatch Documentation - Test setup	Form	3min
Abrasion resistance test	- record double abrasions until 2 string breaks. - Repeat X2 with new swatch	Form	20min
Graphing	- visually represent data	Graph	3min
Take down	- Remove materials from testing device		2min
Graphing	- visually represent data	Graph	3min
Take down	- Remove materials from testing device		2min

HWK Textile Motorcycle Jacket
$60

Alpinestars Bionic Tech V2
$300

Armored Reflective Jacket
$250

Part: Visibility Jacket

Product: *HWK Textile Motorcycle Jacket*

Strength	- High visibility strips are on all sides of garments. - Panels of high visibility are stylized as part of the wholistic design.
Weaknesses	- High visibility strips are small. - High vis strips on back will be obscured by bag.
Opportunities	- White paneling can be traded out for high vis for an anatomical visibility - Powered lighting can be integrated for visibility without the need for reflection.
Threats	- High visibility areas do not resemble a human when taken out of context.

Product: *Alpinestars Bionic Tech V2*

Strength	- High vis blocking is integrated into branding
Weaknesses	- High vis paneling is extremely limited and hard to see
Opportunities	- High vis branding can be made larger and dynamically places for on trend look.
Threats	- Overall black coloring hides user at night. - Inadequate high vis paneling is dangerous in nighttime conditions.

Product: *Armored Reflective Jacket*

Strength	- 1/3 of jacket is high vis. - High vis paneling is seen at every angle. - Integrated RECCO® reflector that makes user searchable to the rescuers.
Weaknesses	- High vis paneling does not follow an aesthetic.
Opportunities	- High vis paneling can be made more dynamic - Powered lighting can be added for situations where light is not reflected
Threats	- High visibility areas do not resemble a human when taken out of context.

Part: Impact Protection Jacket

Product: *HWK Textile Motorcycle Jacket*

Strength	- CE armor on the shoulders, elbows, and back made of high-density foam padding. - Padding can be replaced
Weaknesses	- High density foam is not preferred by motorcyclists - Padding does not prevent dangerous movement in the spine - Padding is not zoned for EUC riding.
Opportunities	- Further development of padding or partnering with another manufacture could improve product.
Threats	- Padding in garment is likely to be replaced for a higher performance alternative.

Product: *Alpinestars Bionic Tech V2*

Strength	- Alpinestars is a trusted brand in protective equipment. - Viscoelastic padding allows for mobility and impact protection as needed. - The padding is porous and allows for ventilation. - Padding is strapped in place against the body.
Weaknesses	- Padding is not zoned for EUC riding.
Opportunities	- Padding could be zoned for EUC and motocross riding in the same garment.
Threats	- Padding is not replaceable, so it becomes a garment with a limited life expectancy.

Product: *Armored Reflective Jacket*

Strength	- CE certified level 2 armor. - Armor can be switched out and replaced. - It is easy to order replacement parts.
Weaknesses	- Loose fit allows padding to move around in an accident. - Padding is not zoned for EUC riding.
Opportunities	- Changing the silhouette of the garment will make the padding more effective.
Threats	- Back padding is to small to provide adequate spinal protection.

Part: Abrasion Resistance Jacket

Product: *HWK Textile Motorcycle Jacket*

Strength	- Jacket can be zipped into pants for better abrasion resistance. - Double stitching is used. - polyester 600D Cordura fabric is used in high abrasion areas in the outer shell
Weaknesses	- Jacket does not have a CE abrasion resistance rating.
Opportunities	- The same zoning principal can be applied with higher performance fabrics and made specifically for EUC riding.
Threats	- Garment trades off performance for low cost.

Product: *Alpinestars Bionic Tech V2*

Strength	- The outer casing is highly abrasion resistant.
Weaknesses	- Jacket does not have a CE abrasion resistance rating. - The fabric panels between the armor are not abrasion resistant, making the garment have a limited life expectancy.
Opportunities	- This level of protection can be combined with some of Alpinestars other performance jackets to make a garment that is more durable.
Threats	- It is at a high price point for a garment that is not meant to be worn on the road but on loose terrain. This means that the garment would fall apart easily when abraded.

Product: *Armored Reflective Jacket*

Strength	- Garment is certified as motorcycle protection with classification EN 17092-4:2020 Class A. - The internal stitching of the garment has "overlock stitches" for increased durability
Weaknesses	- A rating means it will only be suitable for EUC riders going under 28mph. - Only the inner layer is abrasion resistant.
Opportunities	- Changing outer layer would make garment more effective, and allow it to survive multiple crashes - Outer skid areas would make the garment more durable.
Threats	- Only the inner layer is abrasion resistant, making the garment have a limited life expectancy

Part: Jacket Storage

Product: *HWK Textile Motorcycle Jacket*

Strength	- Two zippered external pockets - An inner mobile pocket, and more internal storage pockets
Weaknesses	- Pockets are water resistant, but not water proof. - Zippers leak water - Pockets are made of mesh, not suitable for heady or pokey items.
Opportunities	- Changing out for a water proof material will keep important items safer. - Adding placket behind and if front of zipper will help with leaks
Threats	- Batteries and other sensitive electronics are in danger in the event of rain.

Product: *Alpinestars Bionic Tech V2*

Strength	- There are no pockets.
Weaknesses	- For users using this gear for longer trips, they will need to wear a bag to store personal items.
Opportunities	- Slight adjustments to the waist band area could allow the integration of storage pockets. - A phone arm band would allow users to have access to their speed and wheel metrics on the fly.
Threats	- EUC users need to carry a variety of items like batteries, wallets and their phones on them.

Product: *Armored Reflective Jacket*

Strength	- Two zippered waterproof inner pockets. - Zippers in the front pockets keep items from escaping.
Weaknesses	- Internal pockets are made of mesh, not suitable for heady or pokey items. - Pocket size is limited, reducing the number of carriable items.
Opportunities	- Protecting items in front pockets from abrasion and water would make them more useful. - Gaps in internal pockets for routing cables to phone would make the system more useful for EUC riding.
Threats	- Outer material is not abrasion resistant, being potentially dangerous for items in the front pockets.

Armored Casual
$210

VNfox VES6
$60

Alpinestars Ramjet Air Pants
$250

Part: Pants Impact Protection

Product: *VNfox VES6*

Strength	- CE certified knee and Hip padding - Technically level 2 protection because of the hip pads
Weaknesses	- PU foam is not preferred for impact protection - Padding cam move around a lot in fabric casing
Opportunities	- Material can be changed out for higher quality padding - CE authentication stamp can give users piece of mind.
Threats	- User reviews say the padding feels cheap and has no CE certification stamp.

Product: *Alpinestars Ramjet Air Pants*

Strength	- Removable CE approved knee and shin protectors. - Pocket for optional Nucleon KR hip protector.
Weaknesses	- Knee pads are not able to be reinserted after removal. - Depending on riding position the knee pads can be to low for user.
Opportunities	- Have pants come with padding mentioned in description. - Changing design for padding placement for adjustable height and replaceability.
Threats	- When standing the padding in these pants will be at the shins, and for some EUC riding styles and cruiser seat style bikes the knee padding is inappropriately placed.

Product: *Armored Casual Pants*

Strength	- Pouch for knee pads is large and closed with zipper - Padding is easy to install - Padding does not impact aesthetics
Weaknesses	- Only level 1 pads are included with the pants. - Padding can shift around in pouch in the event of an accident.

Opportunities	- Padding in hips and knees can be changed for level 2 padding.
Threats	- Pants are expensive for limited protection - You have to pay $50 extra for level 2 protection

Part: Pants Abrasion Resistance

Product: *VNfox VES6*

Strength	- This product has no abrasion resistance.
Weaknesses	- Material is cotton and spandex blend, which is not abrasion resistant. - Product does not advertise that any finishes are abrasion resistant.
Opportunities	- Introduction of any abrasion resistance into product would improve performance.
Threats	- This product would not hold up to a crash at any speed, - the padding would be unusable because the material around it would not withstand a crash. - this is a single crash garment and could take the user to the hospital.

Product: *Alpinestars Ramjet Air Pants*

Strength	- Multi-panel construction featuring 450/600 denier nylon panels. - Waist zipper allows connection to Alpinestars leather and textile jackets - Double stitching
Weaknesses	- 450/600 denier nylon is not the strongest material for abrasion resistance - Zoning does not include any segmentation for abrasion resistance as seen in other Alpinestars pants.
Opportunities	- Further zoning can be imprinted and other materials used for increased performance. - Including high abrasion areas as seen in EUC riding can increase user base.
Threats	- There are a lot of other motorcycle pants in this price bracket. - Does not have the same features as some of the other high performance motorcycle equipment.

Product: *Armored Casual Pants*

Strength	- DuPont™ Kevlar® lining helps protect user form abrasion. - Overlock stitching increases durability.
Weaknesses	- Pants do not have a certificate for abrasion resistance. - Outer material is not abrasion resistant.
Opportunities	- Changing the layering of materials would increase performance. - Further development of zoning for high wear areas would improve performance.
Threats	- Pants are at a high price point for the features.

- Pants will have to be replaced at a high frequency because the outer material is not abrasion resistant.

SWOT analysis on pants for storage and visibility is not included as the above mentioned competitors failed to meet these needs. The Alpinestars Ramjet Air Pants was the only product of the three that had a high vis finish on the garment and zippers for pockets. VNfox VES6 has medium to small size pockets with some snaps but no high vis. Armored Casual Pants have limited, unsecure pockets, and no high vis finish.

Fly Racing 5 Pivot
$95.58

Alien Rides Carbon Fiber Knee Pads
$210.00

Leatt Dual Axis
$99.99

Part: Abrasion Resistance Knee/Shin Guards

Product: *Fly Racing 5 Pivot Knee Guards*

Strength	-	Plastic covers shin area.
Weaknesses	-	Only one small point in center of kneecap is abrasion resistant
Opportunities	-	Addition of further knee protection can increase abrasion resistance.
Threats	-	Knee area has impact protection is floating, housed around fabric.

Product: *Alien Rides Carbon Fiber Knee Pads*

Strength	-	40% by weight lightweight carbon fiber
Weaknesses	-	Abrasion resistance is only at the front area of the knee/shin guard.
Opportunities	-	Replaceable zoning could decrease the amount of carbon fiber flaking
Threats	-	Carbon fiber flakes are tricky to get out of wounds.

Product: *Leatt Dual Axis Knee / Shin Guards*

Strength	-	High Density Poly Ethylene, HDPE -
Weaknesses	-	There is no zoning in high wear areas
Opportunities	-	Plastic for abrasion resistance is only at the front of the knee pads, not the sides.
Threats	-	Large sizing range difference makes it difficult to get targeted abrasion resistance.

Part: Articulation Knee/Shin Guards

Product: *Fly Racing 5 Pivot Knee Guards*

Strength	- 5 Pivot design, with unique ergonomic shin pivot, moves with your leg front-to-back, as well as, side-to-side
Weaknesses	- High visibility strips are small. - High vis strips on back will be obscured by bag.
Opportunities	- White paneling can be traded out for high vis for an anatomical visibility - Powered lighting can be integrated for visibility without the need for reflection.
Threats	- High visibility areas do not resemble a human when taken out of context.

Product: *Alien Rides Carbon Fiber Knee Pads*

Strength	- There is a break in the carbon fiber between the knee and shin section
Weaknesses	- High vis paneling is extremely limited and hard to see
Opportunities	- High vis branding can be made larger and dynamically places for on trend look.
Threats	- Overall black coloring hides user at night. - Inadequate high vis paneling is dangerous in nighttime conditions.

Product: *Leatt Dual Axis Knee / Shin Guards*

Strength	- Anatomically correct dual pivot points. - Slim design for use over or under riding pants, fits well with boots
Weaknesses	- High vis paneling does not follow an aesthetic.
Opportunities	- High vis paneling can be made more dynamic - Powered lighting can be added for situations where light is not reflected
Threats	- High visibility areas do not resemble a human when taken out of context.

Part: Comfortability Knee/Shin Guards

Product: *Fly Racing 5 Pivot Knee Guards*

Strength	- 5 Pivot design, with unique ergonomic shin pivot, moves with your leg front-to-back, as well as, side-to-side - CE tested and certified as impact protection: EN1621-1 Level 1 - Impact foam and mesh components line the inside of the knee guard
Weaknesses	- Elastic wears out quickly and is not replaceable.
Opportunities	- Further development of product could allow for articulation while also having that hard impact protection at the knee cap.
Threats	- Comfort at the expense of safety - Design does not accommodate multiple leg thicknesses. - Design does not accommodate differences in knee and shin angle.

Product: *Alien Rides Carbon Fiber Knee Pads*

Strength	- Adjust one time adjustment buckles. - Wear them under or over clothing. - Impact foam and mesh components line the inside of the knee guard
Weaknesses	- There is an edge in the padding that could cause abrasion. - Knee cannot easily articulate
Opportunities	- Increase in thickness of inner padding could increase comfort.
Threats	- Design does not accommodate multiple leg thicknesses. - Design does not accommodate differences in knee and shin angle.

Product: *Leatt Dual Axis Knee / Shin Guards*

Strength	- 1.9 pounds - Impact tested and CE certified to EN 1621-1, Level 1 - Washable Leatt foam - Straps are backed by soft, comfortable, vented airprene material that resists slipping
Weaknesses	- Grouped sizing causes sizing gaps - Adjuster straps are done with single stitching and fall apart quickly. - Adjuster straps cause knee pads to slip down
Opportunities	- Double stitching on straps - Replaceable straps with grip texture
Threats	- Design does not accommodate multiple leg thicknesses. - Design does not accommodate differences in knee and shin angle.

Hillbilly Full Finger Gloves
$44

1Protect All-Weather Gloves Knox
$80

Handroid MK4 Gloves
$300

Part: Glove Articulation

Product: *Hillbilly Full Finger Gloves*

Strength	- Thin material is more like a summer glove, and that increases articulation due to reduced bulk.
Weaknesses	- Leather is stiff when first purchased.
Opportunities	- If thicker materials are used, accordion style pleating can be used for articulation in the fingers.
Threats	- Gloves need to be taken off to use a cell phone. - It is difficult to get jacket on with these gloves.

Product: *Knox Handroid MK4 Gloves*

Strength	- Box finger construction for better fit and feel in fingers. - Touch screen enabled
Weaknesses	- Donning and doffing is difficult with the boa system, making the wrist a lot stiffer as compared to using Velcro. - Thumb is too long. - Fit is tight
Opportunities	- Further development of exoskeleton system will improve articulation. - Changes to pinky sizing will make it easier to use
Threats	- Fit on thumb is long, and interferes with exoskeleton - Exoskeleton on pinky and thumb easily comes out of bracket.

Product: *1Protect All-Weather Gloves*

Strength	- Keeps hands warm in the cold. - Touch sensitive patch on pointer finger.
Weaknesses	- There are currently no reviews on fit. - It looks like gloves would fit like a workwear glove.
Opportunities	- Areas for stretch in the knuckles could improve articulation
Threats	- There are few posted reviews of this product.

Part: Glove Abrasion Resistance

Product: *Hillbilly Full Finger Gloves*

Strength	- Leather side hand and knuckle guard - Plastic wrist guard is replaceable
Weaknesses	- Material is thin feeling compared to motorcycle gloves
Opportunities	- Integration of wrist guard technology into a motorcycle like glove would improve the abrasion resistance of the product.
Threats	- Some users say they feel like gardening gloves - Thin materials make some users afraid to get into an accident with - Zoning is counter intuitive to high areas for abrasion resistance. - Abrasion resistant material cannot be used with a cell phone.

Product: *Knox Handroid MK4 Gloves*

Strength	- 0.8mm kangaroo hide - CE EN 13594- 2015 rating - Idea of finger exoskeleton - Flexible knuckle guard.
Weaknesses	- Finger exoskeleton needs further development.
Opportunities	- Zoning and a wrist guard specific for EUC riding would make this a fantastic product. - There are plastic areas in the gloves that would be zoned for replaceability.
Threats	- Cost is high

Product: *1Protect All-Weather Gloves*

Strength	- Abrasion resistant puck at wrist is replaceable. - Leather is used in construction
Weaknesses	- There is no note about what material is used in the gloves. - It looks like it is made with singe stitching.
Opportunities	- Impact protection with more coverage at wrist. - Integrating is joint protection as seen in motorcycle gloves.
Threats	- This company is small, and not very visible in the market.

Part: Glove Impact Protection

Product: *Hillbilly Full Finger Gloves*

Strength	- Plastic palm and wrist guard helps prevent wrist fractures. - Elastic around wrist keeps wrist guard in place
Weaknesses	- There is no cushioning. - Plastic wrist guard in angled steeply into palm.
Opportunities	- Integration of knuckle guard. - Integrating padding at wrist or where the brace ends in the palm way improve comfort.
Threats	- Some users say they feel like gardening gloves - Thin materials make some users afraid to get into an accident with - There is no cushioning

Product: *Knox Handroid MK4 Gloves*

Strength	- scaphoid protection system - Exo skeleton finger spines which cover the tops of the fingers for impact protection. - CE EN 13594- 2015 certified.
Weaknesses	- Sizing for finger guards and thumb
Opportunities	- There is already padding at the wrist, further development in this area for EUC riders could make this great.
Threats	- High cost for a product that seems like it still needs development in its exoskeleton.

Product: *1Protect All-Weather Gloves*

Strength	- Padding at palm is replaceable
Weaknesses	- There is a small amount of padding at the middle finger knuckle and palm, but not anywhere else.
Opportunities	- Further development is needed to make this a product viable for the speeds and impacts seen in EUC riding.
Threats	- Impact protection does not compare to motorcycle gloves at the same price point.

Part 2

Early Ideation; Materials Exploration, Prototyping and Testing

Materials exploration

Materials and processes under consideration included though not limited to; industrial diamond, ceramic stones or microbeads, reground tire, carbide, combined through casting, 3d printing, screen printing or adhesive. Cordura at 500-1000 Denier was chosen as a base material as it is less expensive than materials like woven blends of UHMWP (Dyneema) but provides better abrasion resistance than Polyamide wovens (Kevlar) the liner in Lazyrolling and other similar products.

Current state of the art materials are produced by companies such as Schoeller Textiles and are woven materials with imbedded ceramic. The processes are proprietary, and the ceramic is integrated into the material in patterns that allow for fabric mobility. Samples of this material could not be acquired, but inspired exploration in additives for fabric to provide zoned abrasion resistance. PLA structures were printed in different shapes to test for flexibility and desired size and thickness. Of these shapes, the triangular array provided the best material flexibility to surface area ratio. The splits in the design can be oriented in the final garments to match the natural bends in the fabric while in motion and at rest. The material was then hot glued to a test swatch for a quick prototype and put through the abrasion machine for testing along with swatches of Kevlar, and a few different deniers of Cordura. This quick run showed that a modified version of the

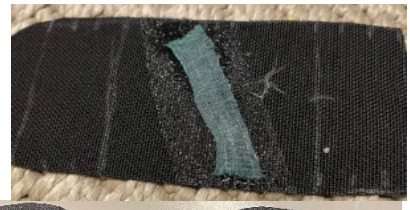
Wyzenbeek test would need to be implemented as the abrasive was being abraded away. In all future tests 80grit alumina zirconia abrasive was used.

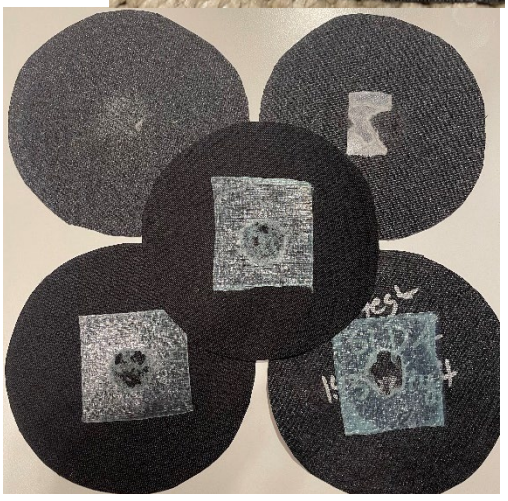
Financial and environmental sustainability was a huge motivator in the decision making of the additive materials. While very cool, industrial diamond, ceramic stones and microbeads were taken out of the running due to being hard to acquire and expensive. Aluminum armor plating was also taken out of the running as milling would cause a lot of waste and the facilities were not available to do the required metal casting. Moving forward, reground car tire, chopped carbon fiber and carbide grit was used as they were cheap, easy to acquire, provided excellent material benefits, and were post-consumer or industrial waste. Carbon fiber is used in many products such as Alien Rides shin guards. As carbon fiber itself may not be highly resistant to abrasion, it was combined with carbide in order to enhance the properties of both materials. Dyneema was later chosen as it could be added to the base material as needed, provide superior abrasion resistance, and be replaced so the whole garment does not need to. One strong reason EUC riders do not use Kevlar lined products like Lazyrolling is because the outer layer is cotton or another not abrasion resistant material. In one accident a $200 item can become useless, making such items financially and environmentally wasteful.

Putting two and two together, we have a variety of different options to choose from. The tire regrind was suspended in urethane rubber, bonding to the Cordura was attempted using; a modified screen printing process, head bonding adhesives and two part contact cement. all of the above failed to adequately adhere to the urethane rubber and Cordura except for screen printing on the non DWR side. This left the material with a very spotted appearance, like peppermint bark, and was decided to be undesirable moving

forward despite it being 4 times as abrasion resistant as the 1.43oz/yd Dyneema option. In was always intended that the rubber regrind, through heat and pressure, be reformed into a desirable shape and applied to the fabric. Non fabric applications would be desired for this material. For those interested in pursuing this further, especially in footwear applications in 2019 Fabrizio Quadrini et al. produced a paper on sustainable molding process for new rubber products from tire recycling.

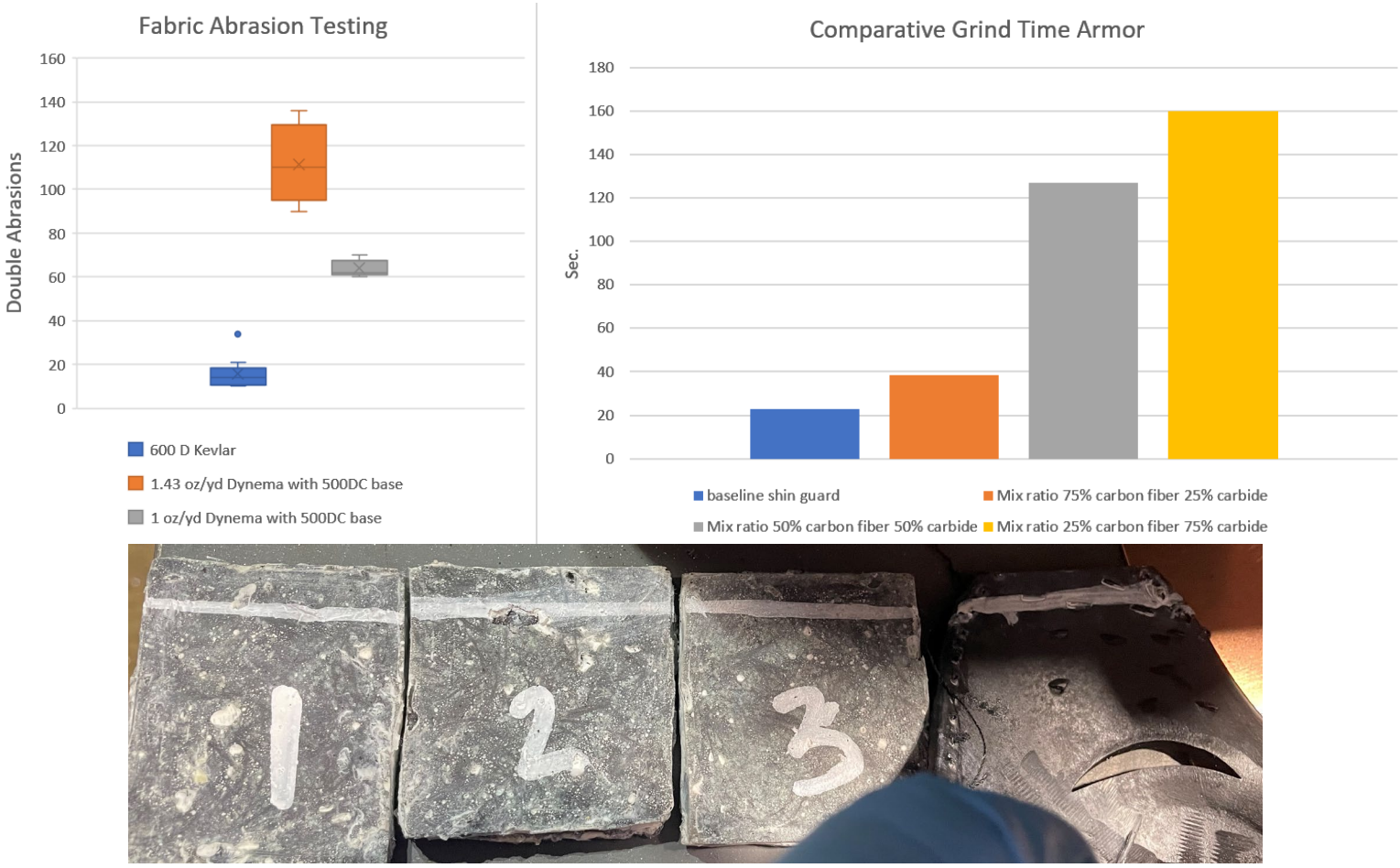
Based off benchmark testing, 3X the abrasion resistance of Kevlar at 60 double abrasions would pass. Of the 5 weights of nonwoven Dyneema tested 1 and 1.43 oz/yd passed. During these tests it was also found that the bond of the Dyneema is equally important, and is affected by the size of the applique and the strength of the bond. A s eparate set of tests was conducted to evaluate the strengths of these bonds. The initial set of tests with Bemis 5274, 3840, and 3825 were all conducted with a press temperature of around 125-130C, any higher and the Dyneema with a melting temperature between 145-155C was liable to deform. While 130C landed within 5274's working temperature range it was found that a pressing temperature of 105-110C and pressure around 50psi bonded the Dyneema and Cordura best. The middle swatch is one such example and lasted 85 double abrasions though only a 0.8oz/yd clothing, showing that both surface area and temperature lead to stronger connections. The upper two samples of are of 1 and 1.43 oz/yd Dyneema additives from the initial tests with 3825 and lasted 65 and 110 double abrasions respectively. The carbide, carbon fiber composite was suspended with Total Boat casting resin and will be used in casting





applications. The percentages of carbide and carbon fiber added were estimated based off volume.

Figure 20: Materials Testing



Kinesiology

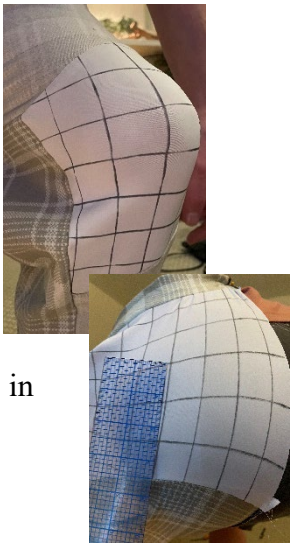
Freedom of movement is intrinsic to this sport, though, ATGATT can interfere with that freedom of movement. Finger movement is one such example, during shadowing users were observed taking off their gloves to grab things like cameras, go through app setting on their phones, and the like. Kinesiology in the glove is doubly important as the top of hand mirror and visibility features interfere with the fabric's natural mobility. Finger hinges were prototyped to

ideate on different methods of providing ease to the fingers .75” of ease was added to the top of the fingers for the pointer, middle and fingers and .5” was added to the pinky fingers bases off of the differences in measurements of an open and closed hand. Of these the accordion and elastic closing pleat were the most successful and continued in development. The accordion pleating can be achieved though heat pressing onto a stretched elastic with adhesive or dividing and sewing the fabrics evenly into 4 parts. A corresponding zipper pull was also ideated upon through forming clay with a gloved hand and selected to assist in opening and closing of zippers. The pocket openings themselves are large, and will easily and comfortably fit the glove and other items. The ANKHGEAR MagZip was also used in the jacket as it is an one handed zipper that is easier to handle with gloved hands.

Through user engagement it was found that there was a need in the community for a knee and shin guard with more adjustability. Currently there are no protective manufacturers that make an adjustable hinge which accommodates people with bowed knees or allows the user to adjust the knee section in a way that fits their knees. This leaves a lot of EUC users struggling to find a product that will fit them best and many have to opt for less durable and easy to use options, or none at all. One user did not use knee and shin guards as they were so uncomfortable

to use. A few different iterations of this design occurred, the adjustable section needed to be on the outside of the user so the bulkier hinge did not interfere with gripping on the EUC. The smaller curved hinge ended up being used as it did not take much adjustment to allow for differences in fit. This component will be created in future versions with milled 5mm carbon fiber laminated sheet as it will be able to withstand high amounts of strain, and the scrap can go into the rest of the shin guard. The shape of the knee brace and the organization of panels also had a great impact on ergonomics. Two versions can be implemented, one where the knee cap is on the inside and one on the outside, this will allow for the best adjustment between the two sections. The knee cap section will have to remain small, so the adjacent two sections can be rotated around smoothly and the inner hinge is best with a maximum separation of 2 inches.

Jacket ergonomic prototyping was able to use many of the learnings from the finger hinges. Shoulder mobility is added with a pleated center back which expands when the shoulders move forward. The shoulder is also aided with an encompassing elastic closing pleat which accommodates the rotational movements in the shoulder. When measured with padding, the differences in elbow length between flexion and extension measured 3”. Several iterations of this zone were produced until the optimal shape and accordion pleat placement was achieved. Special consideration was also given to the structure of the jacket bottom to accommodate the squatting motion in emergency breaking. The front opening is in line with the hip joint and the split and pleat in the back allows for rotation and expansion. The height of the jacket in back is also in line with seat height, for those who sit while riding and to ensure the jacket does not get caught in the wheel.



Normally, mobility in motorcycle pants is achieved through a large pant diameter or are performed for the sport. Pants for EUC will need to accommodate both a much straighter stance, have increased mobility in the knees and hips, and be thin enough from the mid-thigh down to work best with knee and shin guards. To understand how the pants needed to stretch in these areas with the included hip padding, gridded 4 way stretch areas were integrated into the pants in the rear and knee in order to measure how, and how much each area needed to stretched. 4 way stretch was brought into the kneecap section as it will be covered by the knee/shin guard and allow adequate stretch in the knee for emergency breaking. Due to the large surface area, an elastic backing was used and stretched to the required amount, 1/8”. Bemis 3825 was applied and laid out with increased spacing where more stretch was needed, when the outer layer with the required ease was applied. The appearance is striped and will be further refined in the future

prototypes. A waistband with G hooks and loops allows the pants to be fitted to the user and not slip during repeated squat maneuvers. The waistband is also the 3rd of three pleats which allows enough room for hip padding while achieving a pleated formal pant feel.

Figure 22: Adjustable hinge prototype left, baseline testing and benchmark joint angles right

Visibility

Bemis Brilliant was used for the retroreflective zoning in all garments. Visible stretch zoning used the pop color blue for easy callout, everywhere else the black Bemis was used to match with the rest of the garment. To zone these areas, photos were taken from a car observing a user in the bike lane. Retroreflective was placed on different areas of the body and areas they reflected were observed and documented.

Several iterations of a glove turn signal were ideated upon. The process began with programing an Arduino to activate an array of lights, this solution was found to be too bright, bulk, and since the light customizing app was not being included in the array of new technology a simpler solution was found. In the workalike prototype, a NE555 Adjustable Resistance Frequency Single Channel was used to get the desired low, high blink time, the resistances were

measured and the desired resistors were soldered in place. Single 1W LED was used with a clear fiberoptic tube which bounced the light in an angled shape to indicate direction. Between iterations the battery was also moved to the upper cuff to allow for a larger capacity battery. A flexible back-of-hand mirror was integrated as part of the housing for the electronics, to replace the glass mirrors currently used by users. Integrated on the side is a 650nm 5mw red laser diode to function as a lane indicator.

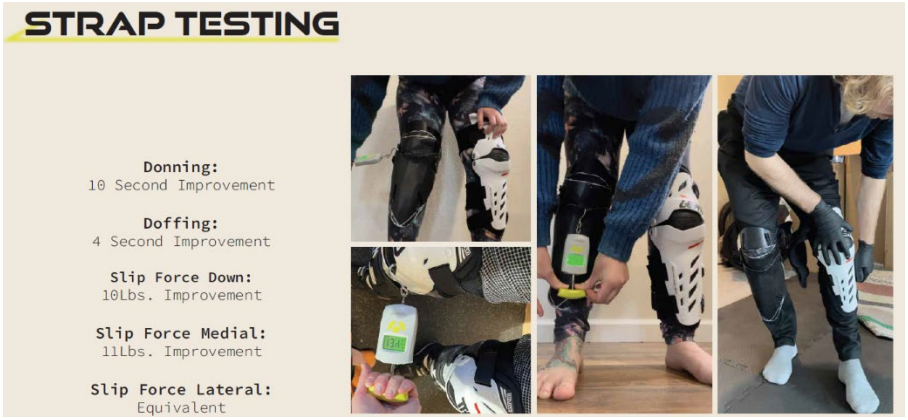
At the time of the workalike prototype the jacket had strips of black Bemis Brilliant in the front and back with 360 fiberoptic with RGB LEDs. There was enough leftover fiberoptic tubing from the glove prototype so it was also integrated into the jacket to accent the yoke while allowing for As most users wear backpacks while riding, special design considerations will have to be taken to have the two function well together, or the backpack can be incorporated into visibility solutions. As it was not a priority for users, the pants and knee&shin guards did not have incorporated visibility however, in part 3 of this paper, retroreflectives will be included in desired areas as a part of branding and styling. The below figure shows the baseline testing, left, and working prototype to the right.

Figure 23: Visibility Testing

Impact Protection

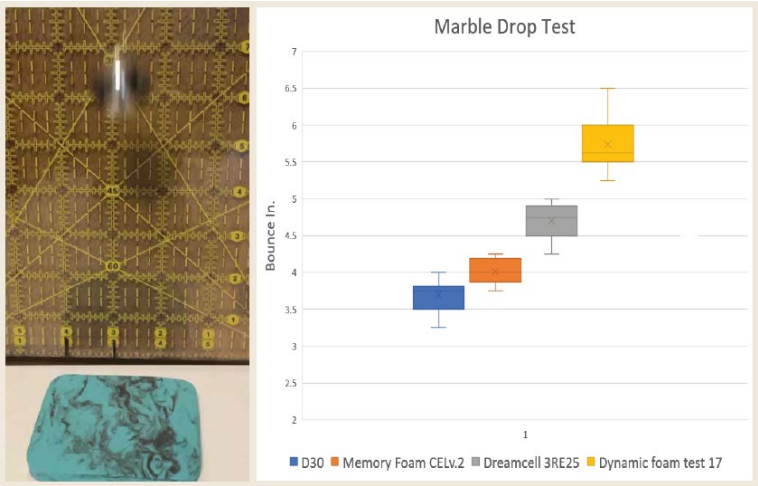
Several versions of the wrist guard were ideated upon, first for mobility in the fingers, then comfort of fit. The best clay prototypes were brought into rhino and from there a few batches of resin printed nylon like models were made. The best shape was brought into Fusion360, optimized and simulated for Nylon12 with a peak impact force of 600 Newtons directly on the palm. 600N was attained as it is the peak impact force of a 170lb person traveling at 50mph and hitting the ground on both hands.

State of the art padding and impact protection right now are special airbag systems that inflate spacer mesh, thus allowing the protection to remain inflated evenly. Though, at this time and for many years to come these systems are impractically bulky and heavy. There is also an important distinction that needs to be made in the mechanics of armor vs padding. Objects like the wrist guard, external plating and certain applications of D30 would be considered armor as these materials take the force of the object and spread that force over the surface of the material. whereas padding is used to increase the time of the impact of the user colliding into the product, and therein decrease peak forces. It was therefore decided that the impact protection in the garments would be a twofold system of a harder, denser, or viscoelastic outer layer with a softer inner layer for that impact delay and a better feel against the body. Manufacturers like Carbon 3D can also make materials and padding systems that provide both viscoelastic, multi directional impact attenuation and better energy absorption because of the multiple surface angles and internal structure. These systems can also be lighter and more breathable than a D30 and padding system however, there is not enough info or easily available materials in order to test their materials.



The external surface for the knee&shin guards will be the carbide/carbon fiber composite with an internal layer of padding. One important factor of impact protection with the knee&shin guards is its ability to stay in place. Currently the Leatt knee&shin guards and similar items will slip to the side, or more importantly down because of strap placement and overall surface area covered. Current knee&shin guards are also optimized for motocross, a sport where the standing position is more bent. This prompted a need in EUC specific strap placement. The Elastic in the straps can also wear out, leaving an unusable but otherwise functional shin guard, because of this, the straps in the functional prototype are attached with Velcro on the inside to prevent any snagging.

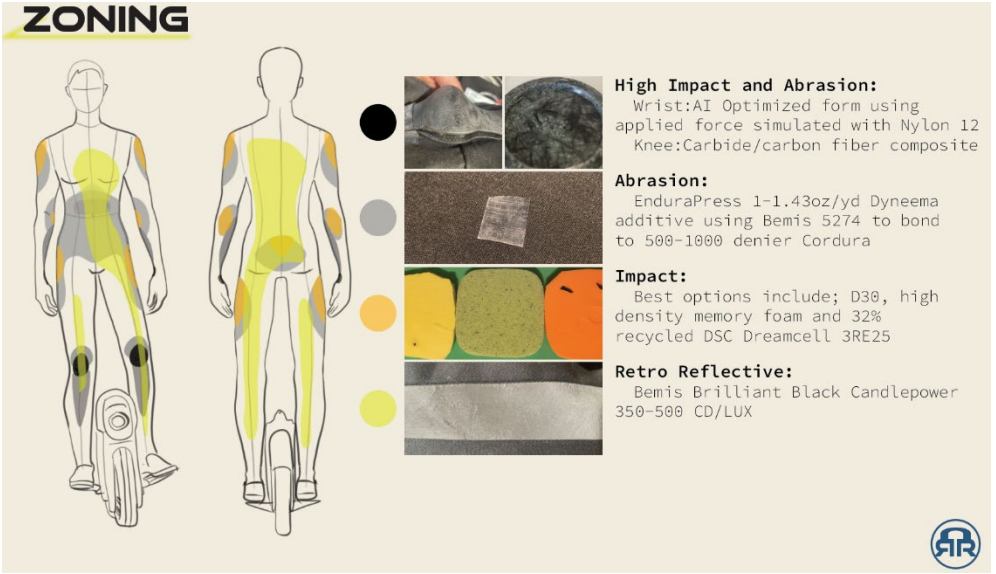
Figure 24: Marble Bounce Testing



Padding testing for this portion was limited to impact absorption of a ball dropped from 24inches. the bounce heights were measured and compared. One huge constraint is that there were no load cells attainable to ascertain a peak imparted force and force curve. Of the 25 paddings tested, D30 and Dreamcell 3R25 from DSC will be used moving forward.

First Prototype Takeaways and User Feedback

In summary, these materials and zones will be used in the final product.



Users liked the stretch areas for the shoulders and elbows and LEDs on the jacket. Users loved the adjustable knee hinge because it provided a natural feeling as fit and straps provide a snug, comfortable, secure feel. Users also really loved the lower fit of the wrist guard for improved finger mobility and grip. The turn signal was a hit but some were wondering if there is a way to get the fiberoptic at the back and front of the hand. The mirror was also much appreciated. The fit on the bottom of the plants needs to be widened to allow for better donning and doffing. The waistband G loop was also brought back more based off of user feedback and eliminated the gap in the back that occurred for some. The adjustability of the waistband was appreciated as well as the hip and tailbone padding. Based off of final review feedback, the lane laser line will most likely be moved. Overall, the feedback received was overwhelmingly positive and what needs to be changed and refined is attainable.

Part 3

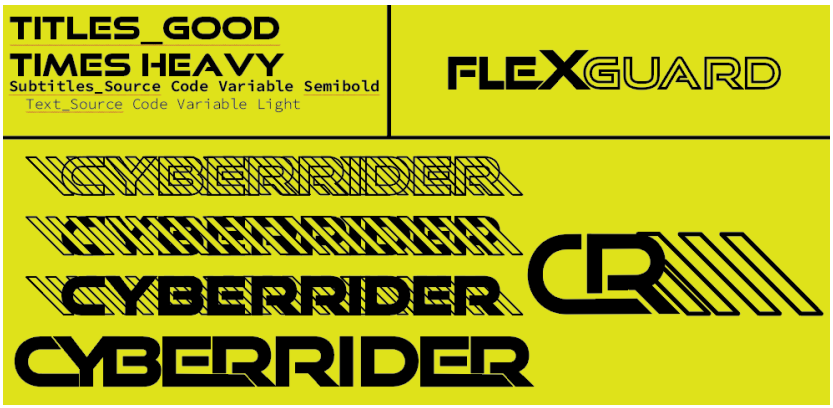
Design Finalization, Testing and User Feedback

Design and Branding

Due to the new man and machine nature of this sport, a cyberpunk aesthetic was used for inspiration. As users do not want to look like motorcyclists, new silhouettes and design inspiration were generated using Stable Diffusion. Prompts were refined until the aesthetic was realized, negative prompts for guns and firearms needed to be used. In order of weight the prompts were: Full body shot of a neon futuristic solider man, cyberpunk, shoes, realistic face, hacker coat , futuristic cityscape, portrait lens, cyberpunk setting, neon lighting, highly detailed, digital painting, artstation, smooth, sharp focus. The mood board is nontraditional, evoking the creativity and energy in this sport.

Prototype set 1 used hard angles and style lines which were too busy, when all elements were brought together. Quite a bit of design refinement was needed to concisely represent the needs of the sport but retain visual interest. New silhouettes were voted on by members of the cohort and the winners were further refined and voted on by athletes.

Branding and logo ideation started pretty rough but was further refined for a clean and arithmetically consistent finish.



One excellent attribute of Dyneema is it uptake of sublimation. This will allow for individualization through graphic applications on the high abrasion areas, users like the idea of being able to pick something for them selves from a set of graphics.

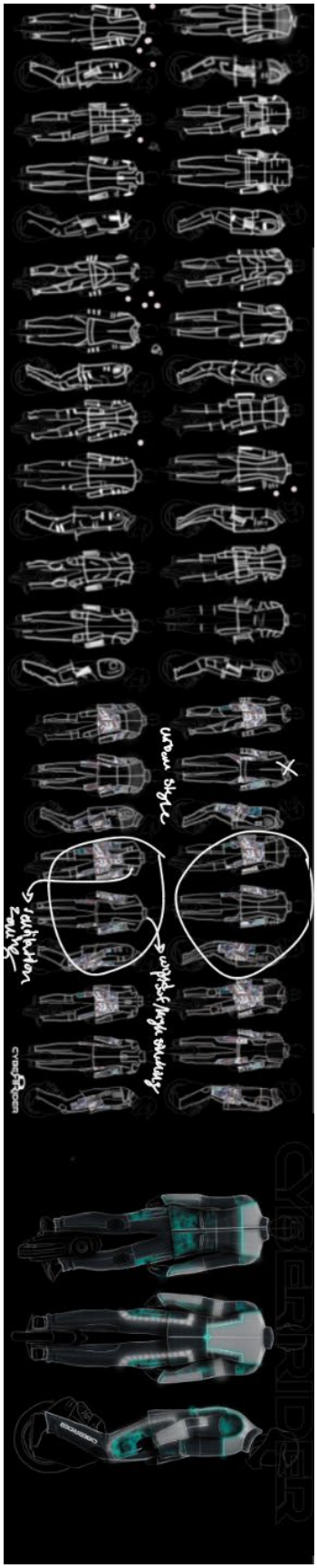
Jacket Refinement

Mobility in the jacket overall was great from prototype 1-3. The mobility features between prototypes 1-2 did not change but prototype 2 was made with the final fabric. in user testing it was noted that the sleeves felt stiff, though the stretch zoning was placed correctly. To reduce buck between versions 2-3 500 instead of 1000D was used in the sleeve. Flex groves were also added to the Dyneema as a functional graphic and is meant to be inline with the shattered glass aesthetic.

The high visibility features changed a lot between the prototypes. Prototype 1 had a hand sewn fiberoptic, in prototypes 2-3 it was changed out with a sewn in fiber optic piping. The Dyneema ended up being reflective and visible in low light situations when there was a light source. For a prototype 4 it would be interesting to layer retro reflective behind the Dyneema applique as it is translucent and could potentially reflect through the Dyneema. Changed were made to side view retro reflection between prototypes 2-3 to increase user visibility at intersections.

Ventilation is considered valuable by users so it was added between prototypes 1 and 2, this was a difficult situation to rectify as the front opening interfered with the stretch zoning in the front of the garment. So, between versions 2-3 the size of the stretch paneling in the front of the garment was

reduced in order to make more room. This change did not affect the perceived stretch in the underarm or when rotating the shoulders back.

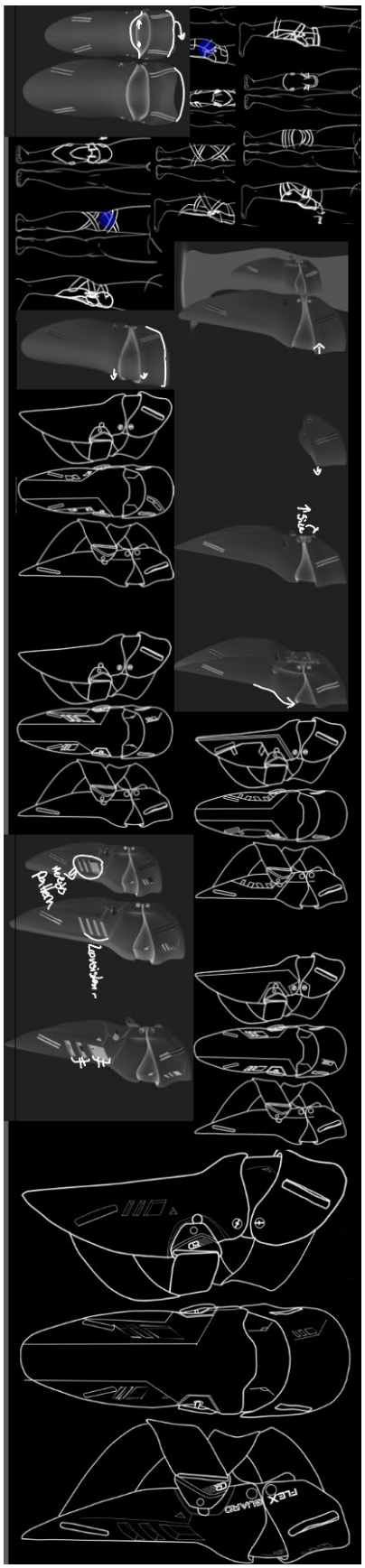


Pants Refinement

Between interactions 1-3 there were a large number of changes made to the pants to improve mobility. Between iterations 1-2 there were a lot of design changes made. The area for the stretch zoning in the knee was made smaller to increase the area of abrasion resistance. The side packets were also added and include the design angle used throughout the product. The pockets feature a fun zipper going along the top and then the side so users can access items in the pockets using gloves. The gusset was also changed from a long strip with bump in the muddle to a more traditional gusset shape, greatly improving the over-all reported baggy fit and feel of the upper section of the pants. Pleats extending down to the lower half of the pant were also included to improve mobility of the hip and padding. The creases of the pants were sewn for a crisp finish

Based on user feedback on pant 2 changes made for the final prototype were more subtle. The shape of the crotch was curved outward a bit more for increased range of motion when spreading the legs. The stretch zone in the knee was brought down one inch and the length of the stretch zone was increased by another inch. The stretch zone in the rear was brought down two inches based off users feeling like it was falling a bit too high and rotating as effectively. The curvature between the back, side back and lower back sections were also brought in to sculpt around the rear. The pockets were ideally placed

but the opening was brought forward and up one inch, this did not change the overall zipper length but it did make users feel more confident in the contents staying within.



Shin Guard Refinement

Further development of the shin guard restarted with rapid refinement and prototyping through CAD and 3D printing. The proportions of prototype 1 were brought into Rhino and sculped around a user's 3D scan. A total of around 7 basic shin guards were printed, changes between these were subtle, the shells were changes slightly in proportion, the interacting surfaces between the shells were brought in or extended and the adjustable hinge was brought in and refined around. The goal was always to improve mobility, the protected surface area and ensure that the shells were not protruding more than necessary so they do not interfere with the EUC's power pads. Generally, the workflow was to clean and construct the prototype in the mid-morning or afternoon, quickly test the prototype, measure the necessary changes, apply them to a continuation of the CAD model and then print the necessary shells overnight.

When the satisfactory setup was found, padding and the previous prototyped straps were applied. custom buckles were made for the specific width of strap, the same brand angle was applied and a metal interface/clip was installed as plastic hardware was reported to break very quickly. Field testing for the full round 2 prototype was conducted and all joint angles could be achieved and no slipping occurred and the new flex guard knee

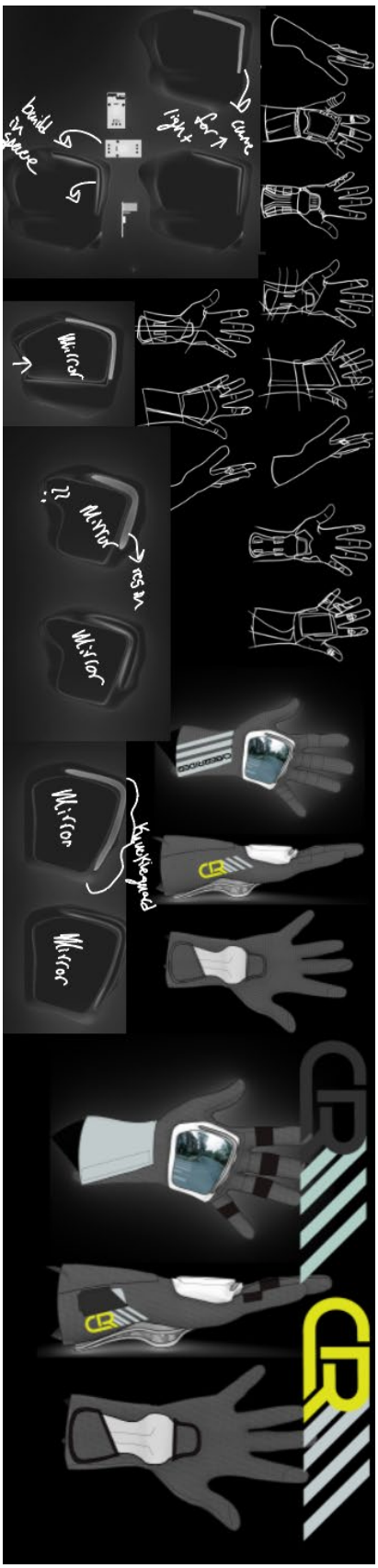
hinge adjuster performed admirably. Design elements were iterated upon by taping and sketching over the round 2 prototype, rounds of sketch ideation and CAD were also performed.

During field testing, the clips would slide and rotate around, bunching the straps along one side so for round 3 indents for the buckles were made. Some mild changes to the upper shell were also made as sometimes the middle and upper shell would stick. The ventilation, brand angle, shapes in the form of vents and MIPS a like were included in the design of the final shin guard. Masters were precision printed, sanded, and used in the mold making process. Flexible silicone molds were made using smooth on mold star 30 so that the casted parts could be removed easily. Cases for these molds were made of plaster to help support the edges of the molds due to the thin nature of the shin guard. Two different casting/layering techniques were used in making the look alike prototypes; one was a premixed wet packing method this came out with some uneven edges where the resin did not fully penetrate to the second method involved more poring and layering before packing the rest of the composite. The CyberShield was highly effective in it's abrasion resistance and made post processing difficult. This led to some bulking and unevenness where more precision was needed so the masters were used in the final round of testing. In future versions the CyberShield will be used in zoning where its abrasion resistance is more needed, and the rest will be chopped carbon fiber composite for light weight attributes.

Glove Refinement

The back of hand area went through a number of changes between prototypes 1-3. Between 1-2 the housing was shortened for wrist comfortability, the laser lane line was removed to decrease bulk. Based on user feedback the mirror was made larger, the light up area for the turn signal was made larger and a second LED was added to increase the overall brightness. Between prototypes 2-3 the custom PCB was created, allowing for the electronics housing to

overall be much smaller, the LEDs and new PCB could fit tucked between the curve of the hand and the new, much expanded mirror. The extra space meant that the housing could also effectively be used as a knuckle protector, having room to cover and cup for each knuckle with some adjustments to the height of the channel for the light up turn signal area. Based on user's popular demand the laser lane line was brought back for prototype 3 but was moved back to the side of the wrist.

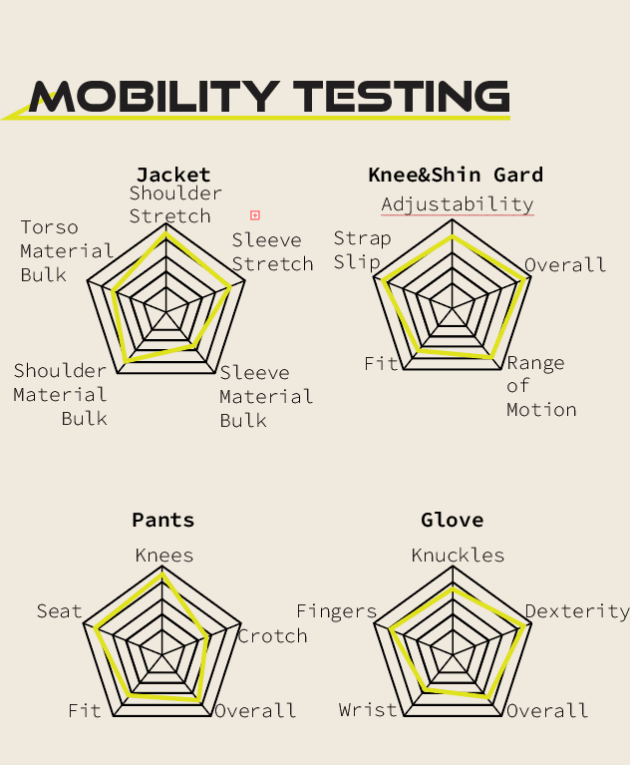


The branding angle motif was pulled into the round area of the wrist guard and no other changes were made as the form and function were already there. Mobility changes in the glove includes lengthening the back for the finger length and, increasing the size of the pattern. Between prototypes 2-3 an additional lengthening was included for the index and ring finger. The liner was also swapped out from the partially stretchy slightly lofted lining to a sleek, 10% stretch poly blend with a cool next to skin feel. The liner changes also improved the touch sensitivity of the glove and no additional conductive fabric was needed.

Final Testing Results and User Feedback

Mobility testing was conducted in the workshop, with users in and out of the field. Joint angles were measured to ensure desired mobility was achieved in and out of the squatting position. The Likert scale was also used and users verbal and written feedback was taken into account when rating each garment. The results are illustrated in figure 25.

Figure 24: Mobility Testing



The shoulder stretch is excellent and so is the sleeve stretch. However, added bulk in the sleeve from the reflective applique reduced points, the overall size could also use to be slimmed down slightly but will still need to accommodate layers used by athletes.

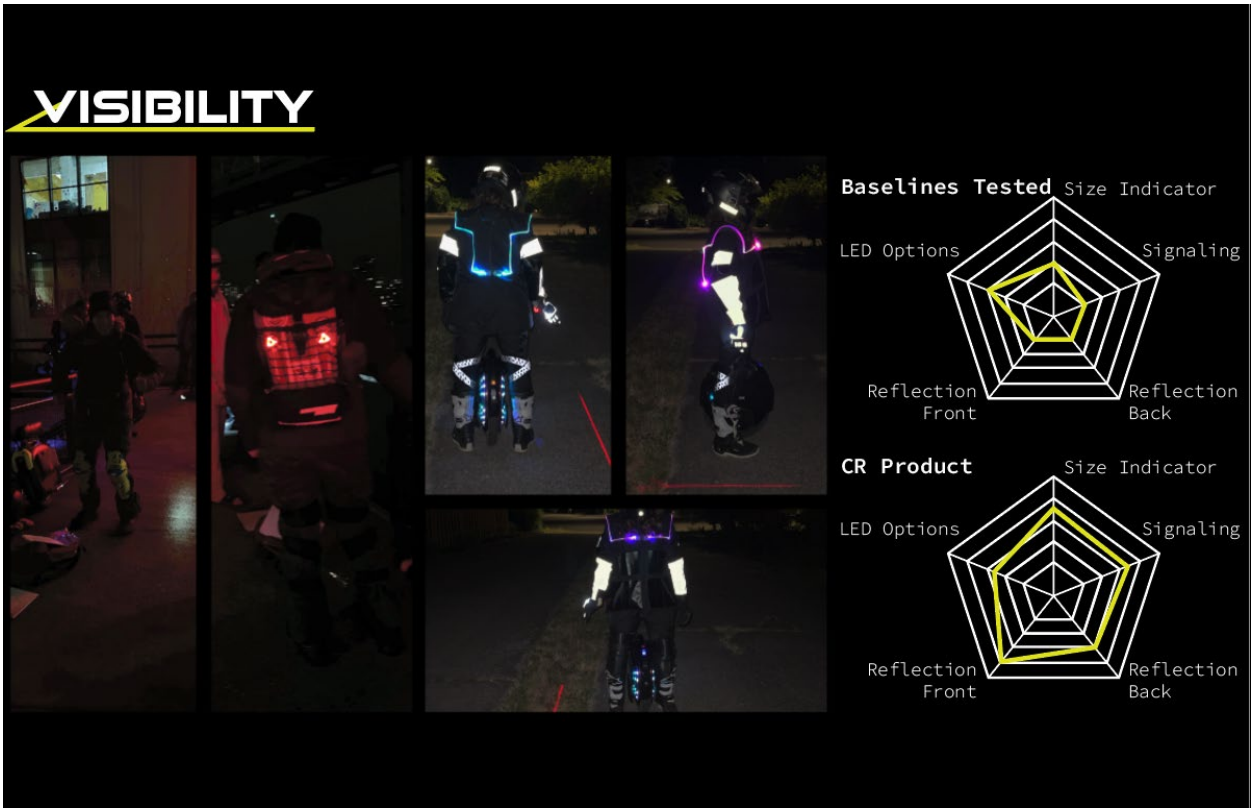
The adjustments to the pants were well revived. Further adjustments will need to be made to the crotch area as the splay with will work for smaller EUCs but can become noticeably tight when dismounting. Everyone has been very pleased with the fit and feel of the shin guards; some adjustments may need to be made to the flaring of the bottom shell's sides. The pants and Shin guards work well together.

The glove flex works well over all and the reduced liner material helps with dexterity. Top of hand pinky section will need to be lengthened but overall the finger and knuckle stretch zoning works well and users who had worn both liked the changes made. The wiring in the wrist pinches slightly and users were wondering about back of hand stabilization so in prototype 4, the wires and micro usb port will be integrated into a back of hand stabilizer.

Side view retro Retro reflection works well for the jacket. Incorporation of side retro reflective branding on the pants and reflective on the straps of the shin guards will need to wait for integration in current prototypes. Front and back retroreflection in the also greatly improved

from baseline and was well received but could use some improvement. Users love the fiberoptic, laser lane line, and turn signal but all could to be brighter especially the turn signal. The clear resin printed fiber optic was not high enough quality to rout light effectively so higher quality and the ends were roughly cut, meaning the light is not passing though as well. Figure 26 shows the Likert impressions of the visibility in the garments. higher visibility and daytime visibility can be achieved through brighter colorways. Overall there was a huge amount of support and encouragement from the community for this project.

Figure 24: Visibility Testing



About the Author

My strengths listed through strengths finder are: 1 Achiever, 2 Input, 3 Learner, 4 Restorative and 5 Intellection. All of these strengths align perfectly with my thesis. The achiever strength will keep me going and pushing myself and my thesis design over this year. My

restorative skill will help me find solutions to the problems my athletes face. My input, learner and intellection skills will allow me to learn, understand and organize the information that I will be taking in over the course of this thesis to make relevant product. I would like this thesis to highlight my talents as a holistic designer, as I explore both materials and design to answer the needs of athletes. Equipment for EUC riders will also align with the motorcycle product space, an area that I would be happy to design for. I am also interested in apparel and equipment innovation, and I think that the fun, out of the box nature of this project will align with this space.

Special thanks to RuBen Permel, costume designer and currently Wardrobe Supervisor The Beatle's LOVE at Mirage at MGM Resorts International, and Ryan Henry, Design Director, Garment and soft goods design at Seismic for agreeing to be mentors on this project. Thank you to all the passionate EUC riders that have taken the time to be a part of this project, you all are what make our work worth it!

References

1protect all-weather gloves. 1Protect. (n.d.). Retrieved November 18, 2022, from https://1protect.co/collections/1protect-all-weather/products/1protect-all-weather-gloves

9 common knee injuries from fall. AICA Atlanta. (2022, August 27). Retrieved November 11, 2022, from https://chiropractoratlanta.com/9-common-knee-injuries-from-falling/

Alien rides carbon fiber protective elbow and knee pads. Alien Rides. (n.d.). Retrieved November 18, 2022, from https://alienrides.com/collections/alien-style/products/carbon-fiber-protective-knee-elbow-pads

Alpinestars 6506520-13-XXL bionic tech v2 protection jacket ... Amazon prime. (n.d.). Retrieved November 18, 2022, from https://www.amazon.com/Alpinestars-Unisex-Adult-Bionic-Protection-one_Size/dp/B07TFKD18D

Alpinestars Ramjet Air Pants. RevZilla. Retrieved November 18, 2022, from https://www.revzilla.com/motorcycle/alpinestars-ramjet-air-pants

ARnaldo. (2022). *VID 20220221 061824*. YouTube. Retrieved November 11, 2022, from https://www.youtube.com/watch?v=qez6EohDOEo.

Bay, M,A. (2005). *Hybrid Ventilated Garment* (US 2005/0235392 A1). United States Patent Application Publication. https://patentimages.storage.googleapis.com/28/e0/c5/a2669293c5aff7/US20050235392A1.pdf

Browning, C. (2022, April 6). *Key Prints & Graphics: Women's & Men's Active A/W 23/24*. WGSN. Retrieved November 11, 2022, from https://www.wgsn.com/fashion/article/93466

Browning, C. (2022, September 14). *Key Prints & Graphics: Women's & Men's Active S/S 24*. WGSN. Retrieved November 11, 2022, from https://www.wgsn.com/fashion/article/6304f7319a8d1cf02b4e62a8

Canada's Motorcycle, C. M. (2015). *What Motorcycle Armour is Best? YouTube*. Retrieved October 27, 2022, from https://www.youtube.com/watch?v=-e6Jy69mezg.

Chang, J. (2020, November 17). *Top 6 electric unicycles by price per range*. Electric Unicycle Guide. Retrieved October 12, 2022, from https://eucguide.com/top-5-electric-unicycles-by-price-per-range/

Chang, J. (2021, April 12). *Why Portland is the best city for Personal Electric Vehicles*. Electric Unicycle Guide. Retrieved October 12, 2022, from https://eucguide.com/why-portland-is-the-best-city-for-personal-electric-vehicles/

Motoruota, C. (2022, April 11). *M O N O W H E E L S* . Monowheels. Retrieved October 12, 2022, from http://www.douglas-self.com/MUSEUM/TRANSPORT/motorwhl/motorwhl2.htm#gara

DeGoede, K. M., & Ashton-Miller, J. A. (2002). Fall arrest strategy affects peak hand impact force in a forward fall. *Journal of Biomechanics*, *35*(6), 843–848. https://doi.org/10.1016/s0021-9290(02)00011-8

Downs, R. Adams, C. Holweger, J,M. Hatcher, W,E. McDaniels, K,J. Meldner, H. (2019). *System and Methos for Producing Three-Dimensional Articles From Flexible Composite Materials* (US 10 , 189 , 209 B2). United States Patent. https://patentimages.storage.googleapis.com/da/d6/3d/98aa92db742013/US10189209.pdf

Edwards, M., & Arnaldo, M. (2022, September 27). Introductory Interview on The Needs of EUC Riders. personal.

En 13595-1: 2002protective clothing for professional motorcycle riders - jackets, trousers and one piece or divided suits. SATRA. (n.d.). Retrieved October 20, 2022, from https://www.satra.com/ppe/EN13595.php

Euphoric. WGSN. (n.d.). Retrieved November 11, 2022, from https://www.wgsn.com/fashion/article/88073#page_1

Exercise Benefits With Proper Form & Technique Side Step-up. Home Gym Exercises. (n.d.). Retrieved November 11, 2022, from https://homegym-exercises.com/side_stepup.html

Giustino, M. (2022, September 23). *Key Trend 2022: #RacerRevival*. WGSN. Retrieved November 11, 2022, from https://www.wgsn.com/fashion/article/632394bf6f715ca5a674278a

Go George Go!! (2021). *The Speed Wobbles and Rider Mentality - Electric Unicycle Tips and Tricks - Euc Learning Series*. *YouTube*. Retrieved November 11, 2022, from https://www.youtube.com/watch?v=sYIHI-z4Vdw.

Harley-Davidson Motor Company. (2021, March 2). *New neurobiological study finds riding a motorcycle can decrease stress and improve mental focus*. Newswise. Retrieved November 11, 2022, from https://www.newswise.com/articles/new-neurobiological-study-finds-riding-a-motorcycle-can-decrease-stress-and-improve-mental-focus#:~:text=While%20riding%20a%20motorcycle%2C%20participants,light%20exercise%20and%20stress%2Dreduction

Hillbilly full finger gloves. e-rides. (2022, November 15). Retrieved November 18, 2022, from https://e-rides.com/product/hillbilly-full-finger-gloves/

How It's Made. (2012). *How It's Made - Motorcycle Jackets*. *YouTube*. Retrieved October 27, 2022, from https://www.youtube.com/watch?v=klQ0zkxbesM.

Protective Wear for Reducing Trauma to the Human Body (US 2016/0174641 A1). United States Patent Application Publication. https://patentimages.storage.googleapis.com/bb/b1/c2/4e595fd1d38d31/US20160174641A1.pdf

Kostiak, Y. (2021, May 10). *Active Colour Forecast S/S 23*. WGSN. Retrieved November 11, 2022, from https://www.wgsn.com/fashion/article/90783

Knox handroid mk4 Gloves. RevZilla. (n.d.). Retrieved November 18, 2022, from https://www.revzilla.com/motorcycle/knox-handroid-mk4-gloves?irclickid=wIVSEn108xyNWqURvYS8SxW0UkDVDZSk00000w0&irgwc=1&utm_source=Impact&utm_medium=affiliate_&utm_campaign=2242980&utm_term=Tangible day

Krag, G. (2022, February 22). *Project & Agenda A/W 22/23: Men's Prints & Graphics*. WGSN. Retrieved November 11, 2022, from https://www.wgsn.com/fashion/article/92790

Łastowski , S. (2022, September 5). *Ministerstwo infrastruktury Dopięło Swego. Praworządnych Użytkowników Elektrycznych monocykli I Hulajnóg Czeka poważne wykluczenie*. Na jednym kole. Retrieved October 20, 2022, from https://najednymkole.pl/ministerstwo-infrastruktury-dopielo-swego-praworzadnych-uzytkownikow-elektrycznych-monocykli-i-hulajnog-czeka-powazne-wykluczenie/

Lazyrolling. (n.d.a). *Armored casual*. Armored . Retrieved November 18, 2022, from https://lazyrolling.com/products/armored-casual

Lazyrolling. (n.d.b). *ARMORED REFLECTIVE JACKET*. Armored. Retrieved November 18, 2022, from https://lazyrolling.com/collections/all/products/armored-reflective-jacket

Leatt Black Large/X-Large Knee & shin guard dual axis,1 pack. Amazon prime. (n.d.). Retrieved November 18, 2022, from https://www.amazon.com/Leatt-Black-Large-X-Large-Guard/dp/B01M7S0DQF

Leatt, C,J. Macfarlane, S. Steffens, JP. (2016). *Protective Wear for Reducing Trauma to the*

Leighton, K. B., & Silvestro, M. J. (1984, November 27). *Shin guard and method of making - spectrum sports, Inc.*. FPO IP Research & Communities. Retrieved October 27, 2022, from https://www.freepatentsonline.com/4484360.html#:~:text=The%20shin%20guard%20has%20a,then%20cast%20in%20the%20recess.

Men's motorcycle riding pants denim jeans protect pads ... Amazon prim. (n.d.). Retrieved November 18, 2022, from https://www.amazon.com/Motorcycle-Riding-Pants-Protect-Equipment/dp/B08XYZ381V

mrelwood_euc. (2022). *Euc ride modes explained. YouTube*. Retrieved November 11, 2022, from https://www.youtube.com/watch?v=uYYMA-kjueE.

Padway, M. (2021, September 9). *How to choose the safest motorcycle jacket in 2022*. Motorcycle Legal Foundation. Retrieved October 27, 2022, from https://www.motorcyclelegalfoundation.com/choosing-the-safest-motorcycle-jacket/

Padway, M. (2022, September 22). *The Ultimate Guide to Motorcycle Protective Gear*. Motorcycle Legal Foundation. Retrieved October 27, 2022, from https://www.motorcyclelegalfoundation.com/how-to-choose-motorcycle-safety-gear/

Paget, N. (2022, September 9). *Men's Forecast S/S 24: Creative Confidence*. WGSN. Retrieved November 11, 2022, from https://www.wgsn.com/fashion/article/62e7e09dd9d176103118e4da

Parrotte, M. (2022, October 16). *How does motorcycle body armor work?* AGV SPORT. Retrieved October 27, 2022, from https://agvsport.com/blog/body-armor/motorcycle-body-armor.html

Chan, P. (2020, November 6). *Why I decided to start riding electric unicycles and why you should too!* Personal Electric Transport. Retrieved November 11, 2022, from https://personalelectrictransport.co.uk/why-i-decided-to-start-riding-electric-unicycles-and-why-you-should-too/

Protective motorcycle gear: Fabrics explained • pando moto. Pando Moto. (2021, November 27). Retrieved October 20, 2022, from https://pandomoto.com/blog/protective-motorcycle-gear-fabrics-explained/#:~:text=Cordura%2C%20Kevlar%2C%20and%20Dyneema%20are,jeans%20to%20tactical%20military%20jackets.

Quadrini F, Santo L, Musacchi E. A sustainable molding process for new rubber products from tire recycling. *Progress in Rubber, Plastics and Recycling Technology*. 2019;35(1):41-55. doi:10.1177/1477760618798274

Saygi, R. (2021, January 19). *Core Item Update: Men's Active Apparel A/W 22/23*. WGSN. Retrieved November 11, 2022, from https://www.wgsn.com/fashion/article/89908

Schwarze, M., Hurschler, C., & Welke, B. (2019). Force, impulse and energy during falling with and without knee protection: An in-vitro study. *Scientific Reports*, *9*(1). https://doi.org/10.1038/s41598-019-46880-8

Textile Motorcycle Jacket For Men Dualsport Enduro… Amazon prime. (n.d.). Retrieved from https://www.amazon.com/Motorcycle-Motorbike-Waterproof-Armoured-Breathable/dp/B075YT8GB5?crid=6AD6BGVANMHG&keywords=motorcycle%2Bjacket&qid=1644765475&sprefix=motorcycle%2Bjacket,aps,82&sr=8-1-spons&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUE5TkRRRFdLRFRYM1YmZW5jcnl

wdGVkSWQ9QTA4MTY4MDYzREIxNzhGU0c4NU1CJmVuY3J5cHRlZEFkSWQ9QTA1MDA1NDAyN1hETU1OTEhaMEpBJndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ&th=1&linkCode=sl1&tag=tangibleday-20&linkId=0fcd9a5f028bd5c686fca9cf595d114d&language=en_US&ref_=as_li_ss_tl

Tolhurst, J. (2016, November 19). *Lobbying for a change in the law*. jonathantolhurst.com. Retrieved October 20, 2022, from https://jonathantolhurst.com/projects-and-interests/electric-unicycling/lobbying-for-a-change-in-the-uk-law/

Toll, M. (2022, August 15). *Inmotion unveils 'fastest in the world' 87 mph V13 Challenger Electric Unicycle*. Electrek. Retrieved October 12, 2022, from https://electrek.co/2022/08/14/inmotion-unveils-fastest-in-the-world-87-mph-v13-challenger-electric-unicycle/

The Physics of Unicycling. (2012). *YouTube*. Retrieved November 11, 2022, from https://www.youtube.com/watch?v=UzG9_8NgngI.

The Pros and cons of electric unicycles. e-rides. (2022, July 7). Retrieved November 11, 2022, from https://e-rides.com/blog/the-pros-and-cons-of-electric-unicycles/

Vaughn, D. A., Maggiora, M. B., Vaughn, K. J., Maggiora, C. J., Tavakoli, A.-V., Liang, W., Zava, D., Cohen, M. S., & Lenartowicz, A. (2021). Modulation of attention and stress with arousal: The mental and physical effects of riding a motorcycle. *Brain Research*, *1752*, 147203. https://doi.org/10.1016/j.brainres.2020.147203

Winterwheel, & Seba Full Members L 2.2k Location: near Gdańsk. (2020, March 5). *How many of us are there?* Electric Unicycle Forum (euc community). Retrieved October 20, 2022, from https://forum.electricunicycle.org/topic/16945-how-many-of-us-are-there/

The World is Yours. SOLOWHEEL. (n.d.). Retrieved October 12, 2022, from http://www.solowheel.com/brand/

Wyner,D. Fox, R. Cafaro, T. Rogers, S. Newsham, A. Foster, D. (2017). *Flexible Cushioning Pads, Items Incorporation Such Pads, and Methods and Making and Using* (US 9 , 782 , 662 B2). United States Patent. https://patentimages.storage.googleapis.com/8d/ea/6e/a8861bb8d3b34c/US9782662.pdf