APTURE APPAREL

Accessible Athlete Body Positioning Feedback

Assistive Form Analysis Athletic Apparel

Carly Conduff

SPD Capstone

Introduction

Every year, whether it be a national championship, world cup, world series or Olympic games athletes seem to break the boundaries of what was thought was physically possible. While this can be partially attributed to athlete mindset, there is a huge role that technology advancements in training regimen plays. Aspirations of athlete optimization has been driving the field of biomechanics and methods of training for decades. One critical industry to watch in this space is motion capture. As technology increases, the accuracy follows, as does the price point to achieve this. Budget motion capture apps have arisen, but leave require manual post processing, or have high levels of inaccuracies. There has been very little explored in the area of apparel aiding in the function of the technology, rather than an accessory to it. The intent of Apture Apparel to create functional, aesthetic athlete sports product that seamlessly integrates into the accuracy of accessible motion capture as well as creating heightened body awareness to offer positional feedback to young athletes.

Historical Product Background

Sports science has seen rapid growth in the use of motion capture for form and data collection in the last two decades. However, motion capture first got its origins from the animation industry. (Barbour & Schmidt, 2001). There was a desire to capture more lifelike movements in film characters to help humanize them and make them more relatable to their audience.

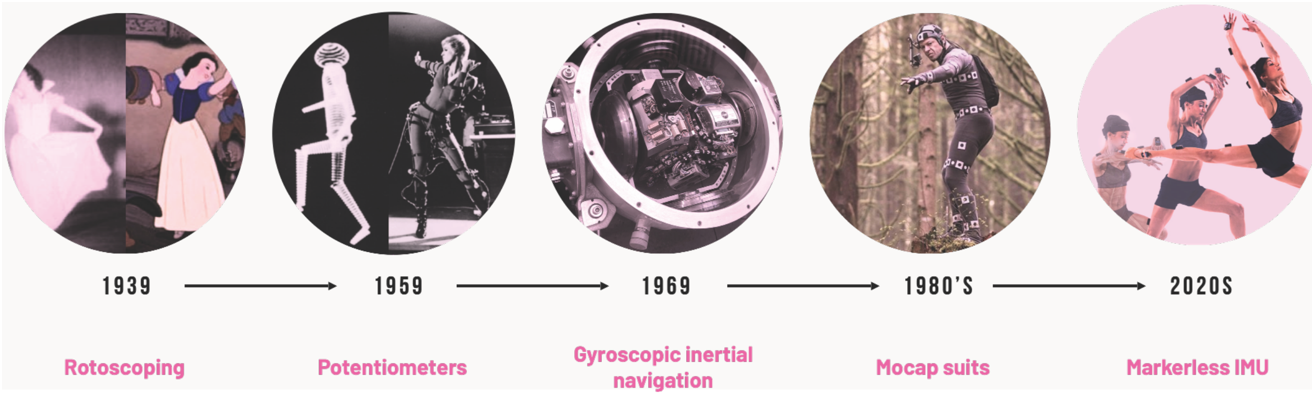


Figure 1 Timeline of motion capture technology.

The first-time early methods of motion capture were observed was Disney's Snow White and the 7 Dwarfs in 1939 through a painstaking process coined rotoscoping (Conditt, 2018). Rotoscoping involved animators standing atop a glass desk and tracing over a projection of a live actor frame-by-frame (Conditt, 2018). The end result would be actors or animals' hand drawn form in a fluid like movement not obtainable otherwise. Though a time-consuming method, it helped Disney obtain its strong presence in the animation world. In 1959, a well-known animator, Lee Harrison III, started experimenting with analog circuits and cathode ray tubes as shown in *Figure 1* (Conditt, 2018). Early computer technology was ill equipped to handle complex images, but this opened up the opportunity for basic form capture on a CRT monitor (Conditt, 2018). Exciting innovations that were implemented in aerospace technology in 1969 paved the way for camera image processing we see today. Motion capture first became apparent in the life science market in the late 1970's (Duffy, 2020). Early adoption for these were intended for gait analysis (Duffy, 2020). This involved a combination of early sensors, computer monitors and cameras (Colyer et. Al, 2018). For a long time in biomechanics research, the process involved manual digitizing of information from photographs. This was a time-consuming task and is susceptible to subjective error (Colyer et. Al, 2018).

The Precision guidance and navigation via a gyroscope-based inertial measurement unit (IMU) was a new technology that contributed to the success of Apollo manned lunar landing on July 16, 1969 (Tazartes, 2014). Gyroscopic technology was founded by the gyrocompass, which uses a single-axis gyro to hold a fixed orientation towards true north developed by Elmer Sperry. (Barbour & Schmidt, 2001). This was the first ability for electronic devices to tell its positioning no matter what orientation the object it is attached to is moving in. By the 80's camera imaging technology was present enough for the development of standard "mocap suits" in the film industry (Wetztein, 2019). The first mocap suits were grey with black and white dots to aid in post processing and placing of joint locations (Wetztein, 2019). Moving to current landscape of this product space, we now see wireless and minimalization of IMU (Inertial Measurement Unit) sensors which combines gyroscopic technology with accelerometers + magnetometers (Wetztein, 2019). These can be placed anywhere on the body by bands or adhesive and can offer real time simulation. Technology to this caliber is difficult to obtain and use accurately.

Product Environment

A significant reason that there is such a barrier to entry to high quality, accurate motion capture is due to the large open space it requires. Three identified arena requirements are displayed in *Figure 2* for optical motion capture.

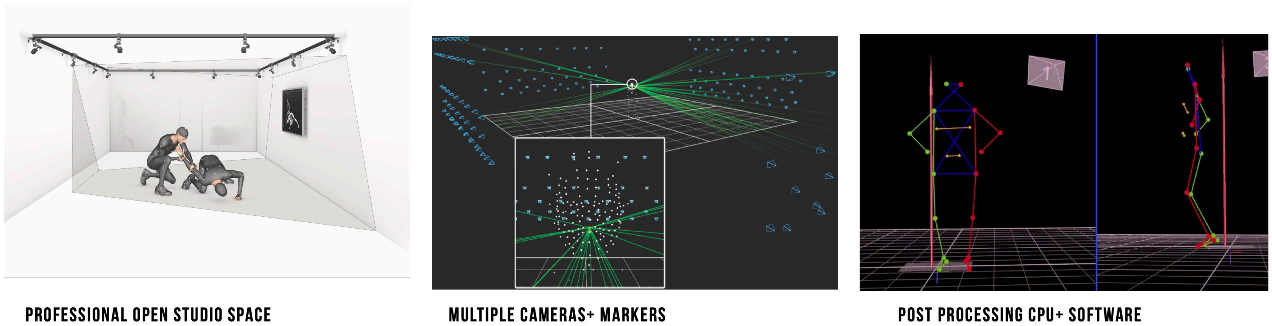


Figure 2 Images of motion capture space requirements.

State of the art systems involve up to 18 cameras mounted around a room. A simple obstruction free space of 12 meters x 12 meters is recommended for initial product systems (Colyer et. Al, 2018). For a student athlete or high school coach operating in multipurpose shared spaces this limits the ability to obtain accurate readings. Even if the space is acquired, algorithmic software programs and post processing abilities need to exist to extract useful data (Colyer et. Al, 2018).

Figure 3 NBA 2k digital asset creation.

Figure 3 displays the use of free unobstructed space, multiple surrounds near infrared cameras and mocap suits with markers used for NBA 2K motion capture (*Motion Capture*, 2017). It is evident that relevant motions for the athlete using these parameters are able to be captured, but at the expense that is not obtainable for the intended user. In moving forward with the thesis direction, a goal of reducing the footprint and requirements of the space that the mocap will perform in will be critical to the success of the project.

Product Success

Understanding what makes a successful wearable product is a critical first step to this project. Many product releases in the wearable technology market have failed for similar reasons. Outside of a research lab, or movie studio, wearables fit into this "fashnology" category. Where the technology of it, useability, and seamlessness is important but so is the aesthetic (Adapa, Siau & Smith, 2018). This is directly applicable to our target user who is an athlete and is concerned with appearance during training. In a study completed by the *International Journal of Human-Computer interaction* data was collected from 25 individuals at a Midwestern technological research university on their interaction with sport tracking wearable devices. It was found that attitude, which was correlated to behavioral intention was driven by perceived ease of use, and perceived usefulness (Adapa, Siau & Smith, 2018). There were additional factors that took into account vanity and need for uniqueness but were not as strongly correlated to behavior as perceived enjoyment (Adapa, Siau & Smith, 2018). In the conclusion of the study results were summed up through the statement: "Wearable devices need to become more intimately connected to our daily lives while combining collaboration, computation, and context awareness in order to enhance personal productivity." (Adapa, Siau & Smith, 2018).

Combining the understanding of wearables, and what it takes for proper adoption, it can then be compared to the goals needed to be achieved through these product offerings. The apparel created will need to visually communicate the function, while still having an approachable useability. The point of the thesis exploration is to enhance personal performance through proper training, so the usefulness case is strong. Ultimately, the product will need to aid in more accurate, on the spot, proper body positioning capture and feedback. The proof of concept at the end of the project will be through athlete/user feedback of tactile and visual elements as well as trials comparing alternative's apparel/technology.

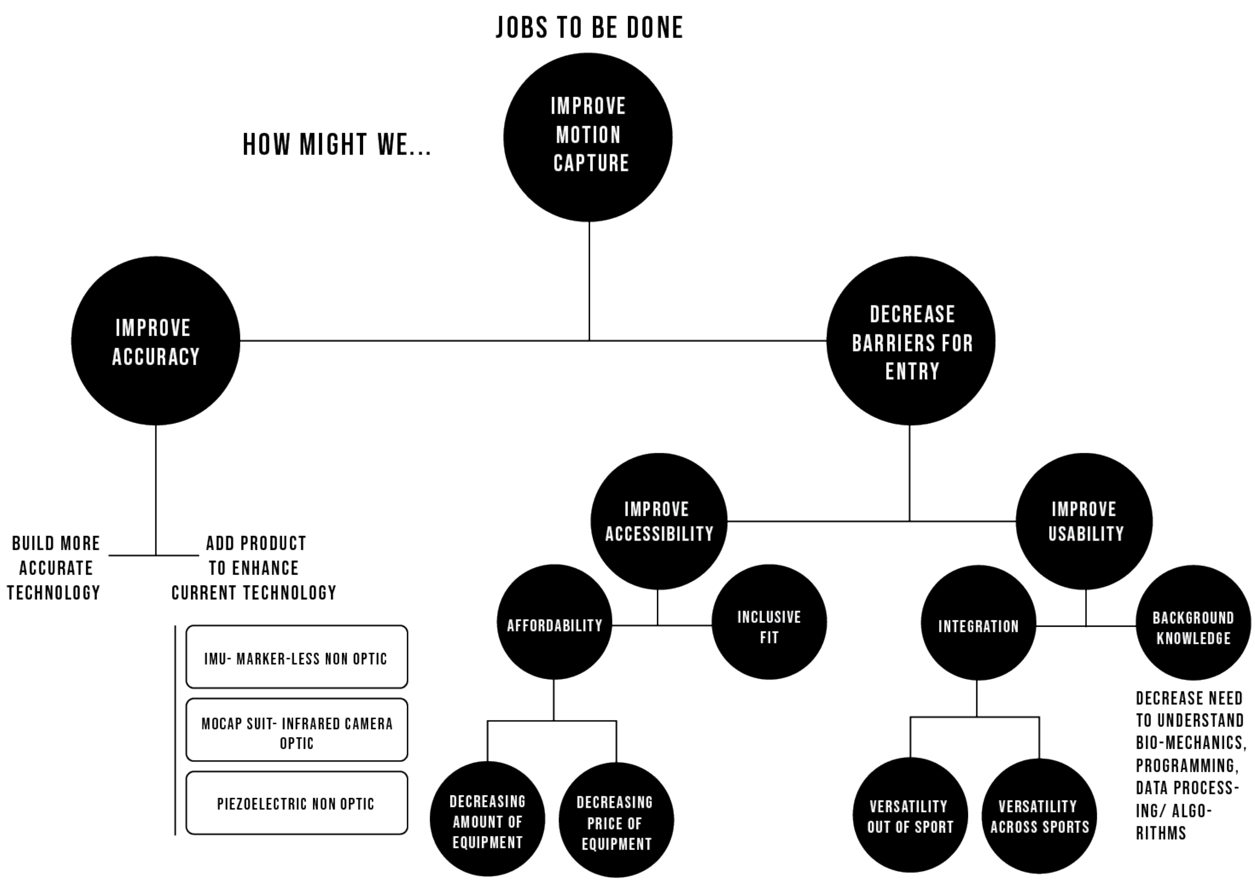


Figure 4 Jobs to be done chart- Motion Capture.

In initial exploration of how motion capture could be improved with in this project scope a jobs to be done tree was built out as represented in *Figure 4*. Two clear pathways to improving the mocap product space were identified as increasing the accuracy of the product or decreasing the barriers for entry. On the left side of the chat, improving accuracy could be approached through developing more technology, or adding product to current technology. The right side of the chart started a deeper exploration of what barriers are currently existing in this space. Two clear issues involved the usability, requiring education on high end technology and the accessibility given the large capital investments and narrow sizing these machines/ suits encompass. While this exploration identified many pathways to explore improving motion capture, finding a solution that utilizes methods to improve accuracy along side methods to decrease barriers for entry would render the most successful end product.

Product User

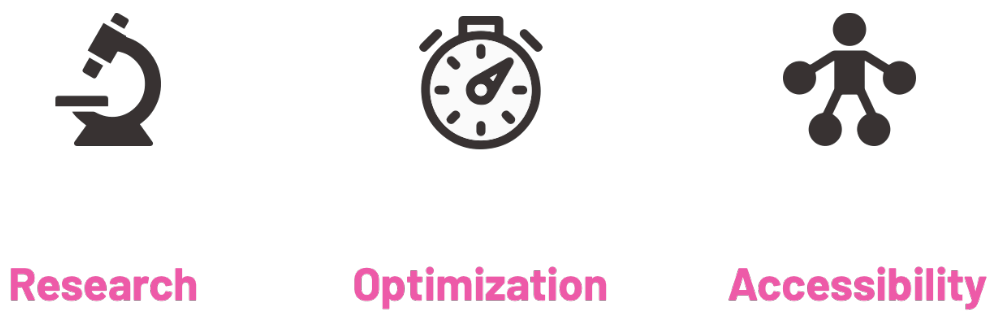


Figure 5 Identified areas of focus with in mocap relevant to user.

Apture Apparel is a concept aimed to target three areas of motion capture as laid out in *Figure 5*. The intended user will have a need for personal, or scientific positional feedback, optimization of form, and lower capital than research labs and pro athletes. Because of the goals that apture apparel is aiming to solve there are two avenues of intended use that is relevant to this space. The first being the student athletes and their coaches. This applies at both an elite high school and college level where they face limited dedicated physical space, and low provided funding. Through this market Apture Apparel could reduce the barriers for young athletes to get real time performance feedback.

A second area of intent with Apture Apparel is sports science education. As the field increases in complexity, having tools available for beginning biomechanics and performance optimization exploration is key for entry to the field. There are promising opportunities for implementation in University & High School physics classes. The collection will have both a men's and women's fit, and for exploration of thesis work the focus will be on throwing a baseball. The application of the technology ultimately not limited to one particular sport application.

The wearable market has seen astounding growth trends that are forecasted to continue for the next 10 years already. As illustrated in *Figure 6* below, the current motion capture market as of 2019 reports was $144 million USD in revenue annually. (*3D Motion Capture Market Size,* 2019). Over the next 6 years the market is anticipated to grow at an impressive 10.09% CAGR from 2019 to 2026 to put the anticipated revenue at $266 million USD by 20206. (*3D Motion Capture System Market worth $266 million by 2025,* 2020).

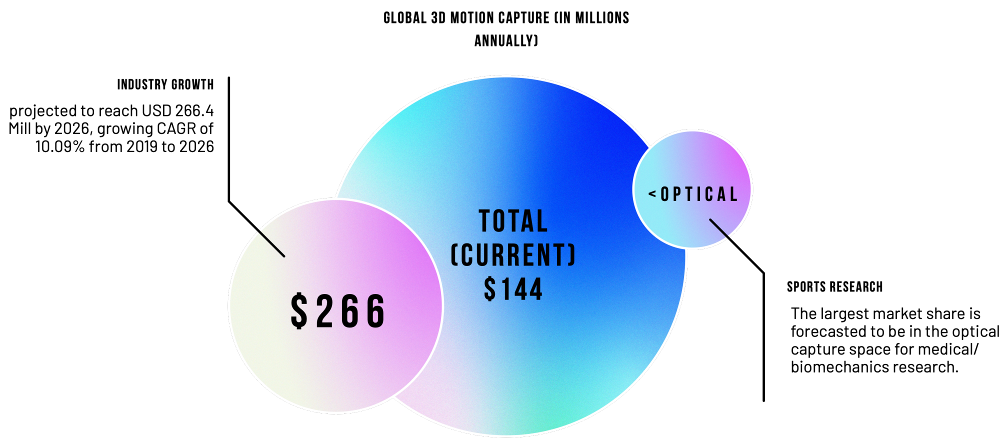


Figure 6 Forecasted mocap/ sports research market estimates.

While the market in whole does included avenues such as film, and 3D gaming asset the primary user of this technology is the biomechanics research industry. (Colyer et. Al, 2018). Motion capture is an essential tool in multiple facets of sports science not limited to biomechanics including sports injury rehabilitation, training and sports performance. The importance of mocap technology is reaffirmed by the increasing number of governing bodies in sport seeking to standardize the various sports performance analysis technologies available to player, coaches and teams. FIFA, a strong governing body in sport announce new global standards for electronic performance and tracking systems (EPTS) (*Changing the game,* 2020). The goal is to ensure the highest quality bar is set, and to offer education and guidance to users in data capture, output and use practice (*Changing the game,* 2020). With large forces creating incentive, equity and standardization this will aid in the growth of the sport specific motion capture industry.

Athlete Positions & Biomechanics

The direction of this capstone project is very exploratory in that there is not a single identifiable set of athlete's problems to solve. The goal of the project is to push the field and technology as far as possible with the goal to improve accuracy and accessibility. There are basic principles of technical sportswear that have not been well executed in competitor products. Athlete mobility, and thermo-regulation will need to be at the forefront of design. Due to the nature of camera processing, there is a high probability the apparel will have to cover the whole torso and limbs. As an athlete is in motion increasing body heat, when they would usually take off layers, this will pose a threat to comfort (Romero, 2020).

For purposes of the 7-month project, it has been decided to focus efforts on one athlete use case for design, testing and validation. As the apparel aims to work to enhance existing camera technology, it has been identified that, repeatable movements with known correct biomechanics will be the best example to test proof of concept with.

Within the scope of the thesis project the focus will be on one case that required identification of whole-body position relative to itself and the ground and a second that narrows down to analyzing a single joint angle. If the product success is reliant on versatility, then this is critical.

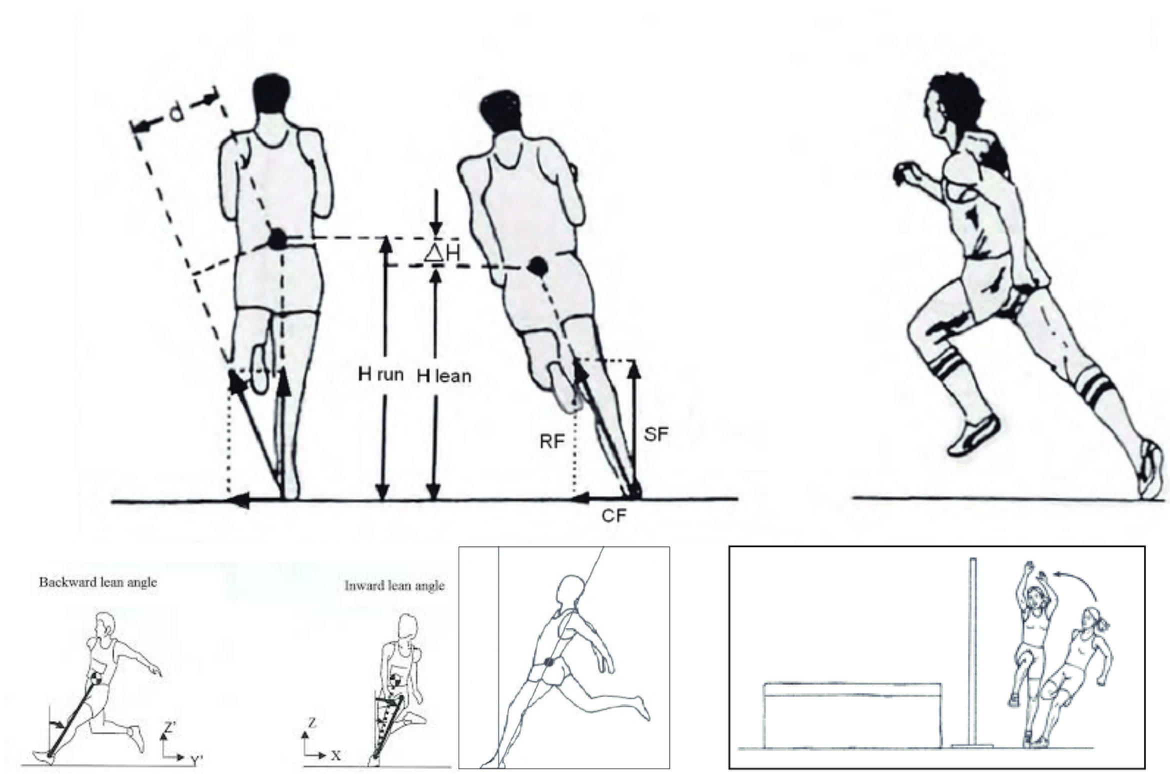


Figure 7 Angles and biomechanics of the Fosbury flop high jump.

High jump is a sport where the axis of the body at different points of the motion is critical to the success of the jump (Leite, 2013). The sport is often not analyzed but required very specific and unique mechanics that provides an interesting use case for the project. Several stages of jump could be analyzed including the axis of lean on the run up, or shoulder position at time of take-off. Examples of these angles are demonstrated in *Figure 7* (Leite, 2013). This requires a wholistic approach to motion capture as the body as an entirety will need to be collected.

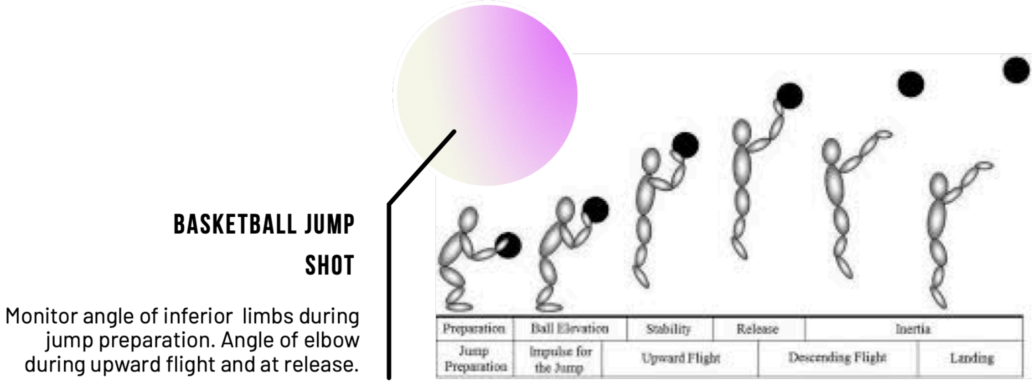


Figure 8 Stages of the basketball shot.

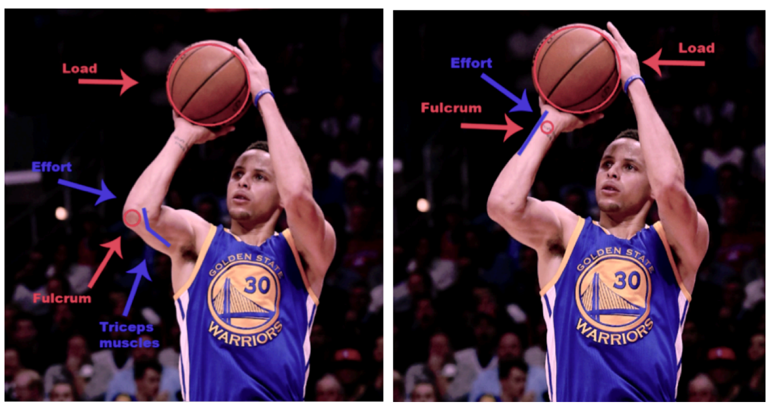


Figure 9 Load and effort during a basketball shot.

In contrast to high jump, shooting a basketball involved areas of the body that can be isolated and analyzed (Kothekar, 2013). Specifically, the angle of the elbow joint as seen in *Figures 8 & 9*. Research has shown that having an angle of 90 degrees in the upward phase of the arm during a shot is most optimal for proper arc and release (Okazaki, 2012). Being able to compare collecting form of a narrow part of the body will be a useful exercise in determining versatility to the user when compared to a high jump.

A second consideration in this field after the sport use cases have been identified is the type of form data that needs to be collected in order to analyze this specified mechanics. State of the art product generally captures either 3D form (volume) or joint locations using markers (Colyer, Evans, Cosker. Et al. 2018). The film industry as well as sport digital asset creation will generally need volume involved. Whereas typical biomechanical research labs generally only need to know the relative position of joints (Colyer, Evans, Cosker. Et al. 2018). The following are methods of capture available:

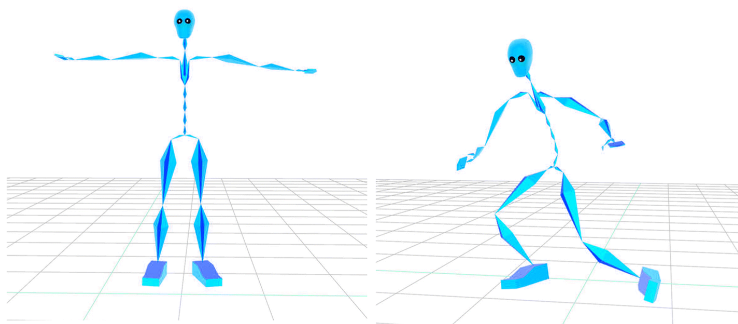


Figure 10 Poseable skeleton model.

“Bones” of a specified length are connected at joints, and rotation of the bones around these joints allows the skeleton to be posed. The skeleton model is commonly utilized in both marker-based motion capture and computer vision-based motion capture systems (Sarto, 2019)

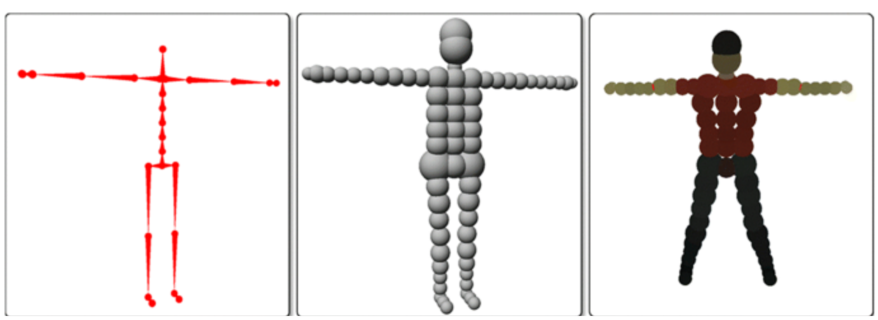


Figure 11 Sum of Gaussian body model.

A skeleton (left) forms the foundation of the model, providing limb-lengths and body pose. The body is given volume and appearance information through the use of 3D Spatial Gaussians arranged along the skeleton (Colyer, Evans, Cosker. Et al. 2018). This allows flexibility in the animation to be fit to image data needed.

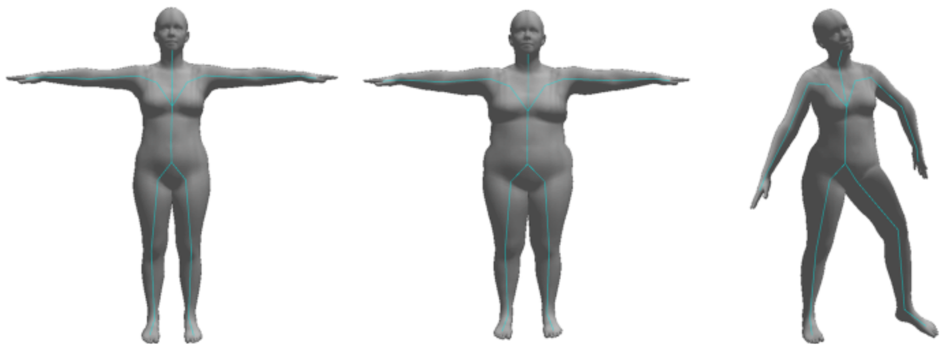


Figure 12Skinned Multi-Person Linear Model (SMPL).

Using this model there is no explicit skeleton. Instead, the surface of a person is represented by a mesh of triangles (Colyer, Evans, Cosker. Et al. 2018). A set of parameters can be used which allows the shape of the model to be changed from a neutral mean (left) to a fatter (middle) or thinner, taller, for purposes of animation (Colyer, Evans, Cosker. Et al. 2018). In terms of sport data collecting, this is the type of form needed to take anthropometric data and capture muscle volume.

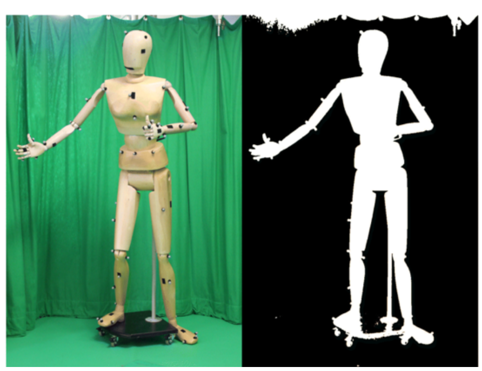


Figure 13 Silhouette on the right from chroma keying the image on the left.

The silhouette model is rudimentary in comparison modern technology but can be effective for certain use cases (Colyer, Evans, Cosker. Et al. 2018). With only the silhouette, it is not possible to infer if the mannequin is facing towards or away from the camera – ambiguity causes issues in analyzing forms but is a very accessible mode of capture (Colyer, Evans, Cosker. Et al. 2018).

For the purposes of capturing a basketball shot and high jump form/ position more information than silhouettes would be needed for the high jump, however silhouettes could work for basketball angling. Volume data is not needed for either sport to analyze form, so these tradeoffs will be taken into account when moving forward with the project.

Relevant Product Space & Anatomy

Within the motion capture market space there are several major components of systems that expand beyond product that is worn on the body. These include: the camera systems that are used, the representation of the human body, the image features used and the algorithms used to determine the parameters of the body model (Colyer, Evans, Cosker. Et al. 2018). These are all categories that are of importance to understand and reference as the project continues. There are several stand out products that exist in the optical camera market from Vicon (reference *Figure 14*), used widely across sport motion capture and biomechanics labs, this product is an aspiration product to the target user (*Vantage: Cutting Edge Flagship Camera by Vicon*, 2020). While can influence the product direction, the focus on product researches for purposes of this paper was put on relevant products geared towards and accessible audience and understanding what accuracy and features these posed. This breakdown is seen in *Figure 15*.

1

5M x 5M Room

8 V5 Cameras

8.5mm Lense

623nm (visible) wavelength

Recommended configuration for athlete movement, biomechanics analysis .

2

High-Speed mode expanding capabilities

1070 FPS

Windowing enables your camera to speed up by narrowing the field of view, ensuring incredible fidelity while tracking high-velocity subjects

3

Onboard sensors, **Infrared LEDs**, and a **digital display** provides system status and feedback

onboard accelerometer, detect when a camera has become misaligned and re-calibrate it

4

Takes the **two-dimensional data** from each camera, **on body markers time-of-flight triangulation** combining it with calibration data to reconstruct the equivalent digital motion in three dimensions

Figure 14 State of art optic technology: Vicon.

RELEVANT PRODUCT LANDSCAPE

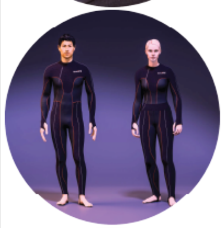
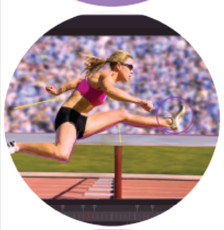
PRODUCT	CLASSIFICATION	COST	PURPOSE	USE REQUIREMENTS	SIZES	COMPONENTS
 ROKOKO	NON OPTICAL IMU	$2500	Entry level IMU technology. Mobility+ ease of use	Wifi Connection, motion software to download post movement	Mens and Womens Small-Large	19 sensors in the suit fabric zipped up in pockets. Power bank. Garment housing.
 SOMAXIS CRICKET	NON OPTICAL IMU	$250 PER SENSOR	Middle range accuracy in Muscles (sEMG), Heart (EKG), Brain (EEG), Posture (Gyr), Respiration (Acc) and Movement (Acc)	Wifi Connection, somaxis app +apparel, more senors for more accuracy	Mens and Womens X-Small-X-Large	Individually sold sensors, apparel w/ Velcro pockets, included app integration.
 QUALYSIS Q-MOCAP SUIT	OPTICAL ADJACENT	$499	State of art suit for mobility and comfort to integrate with infrared markers and camera technology	Markers, mocap camera environment, software for post analysis	Mens and Womens X-Small-X-Large	Individually sold sensors, apparel w/ Velcro pockets, included app integration.
 DART FISH	OPTICAL CAMERA	$60 ANNUALLY	Video analysis solution that allows users to capture & analyze footage on a rudimentary level	Smart phone with camera, laptop or desk top app for increased assessment features	N/A	App with prebuilt algorithms and editing capabilities to overlay on video.
 MICROSOFT KINNECT	OPTICAL CAMERA	$399	Creates 3D forms at Low - Cost and reasonable accuracy (.19m at 7.5 m2)	Computer attachment, pre-bought or self made programming, post image processing	N/A	Projects an infrared laser pattern camera creating 3-D map by measuring deformations in the reference pattern

Figure 15 Accessible motion capture competitor overview.

State of the art Materials & Manufacturing

The breakdown of relevant materials and manufacturing is taken from the lens of product that is going on body. Suits and stick-on infrared reflectors are used frequently to improve the accuracy of capture through integrating with camera technology, or housing sensor IMU sensors (Aouf, 2019). After looking at several major players, and the story of how the company was founded, it is evident that many of these product solutions originated from a tech background, not focused on soft goods or apparel. This was a key insight that was supported in the research of materials and manufacturing. *Figure 16* below breaks down the material component of standard state of art mocap suits, it is noted there is a lack of use of innovative technologies in the apparel industry (*Polymersoluntions.com*, 2014). Typical ranges of material composition rely heavily on polyester (60%), Nylon (35%), Spandex (5%) (Yang, Zhou, Ma, P., 2019).

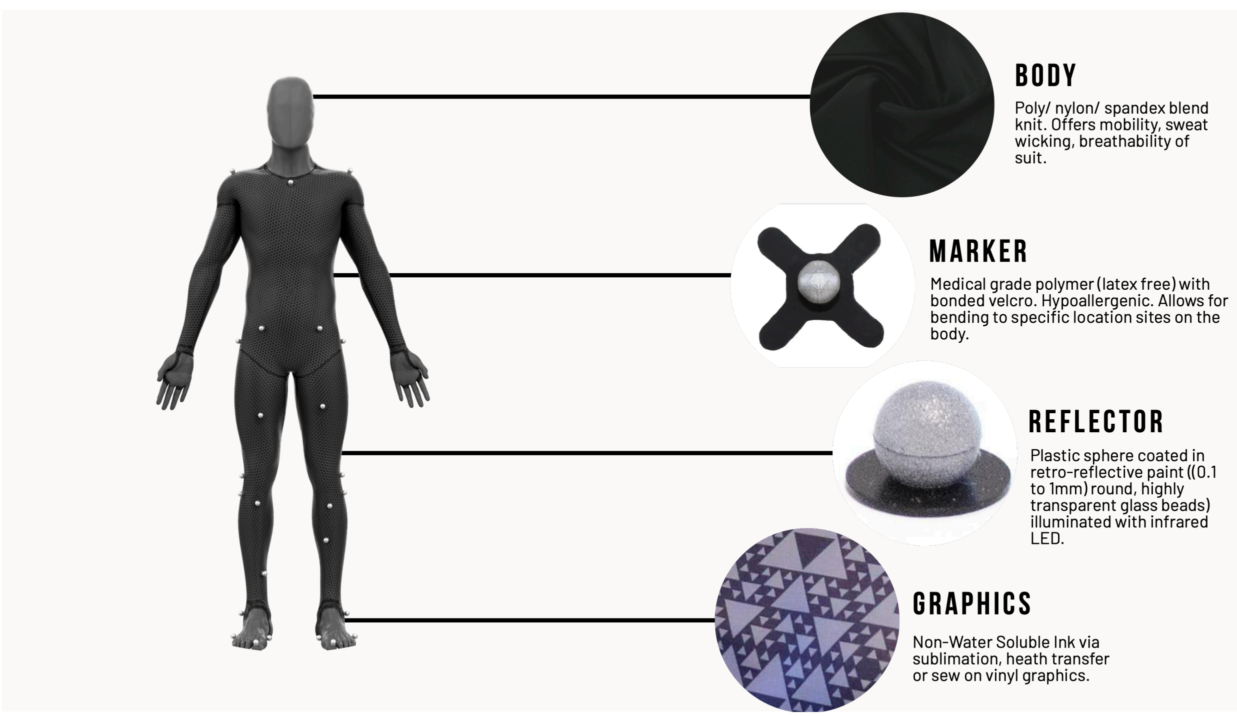


Figure 16 Competitor product material identification.

Further exploration into how these materials are used to produce the garments further supported the identification of lack of technology used in the apparel (Yang, Zhou, Ma, P., 2019). Tricot knitting structures were commonly found across the suits, this is a structure that is standard in base layer athletic apparel. Construction of even newly released state of art mocap suits used questionable seam construction for longevity and practicality of the garment. It has been found that visible seams moving during capture can create issues for post processing and data collection. (Glaeser, et al, 2018). These details are called out in *Figure 17* below.

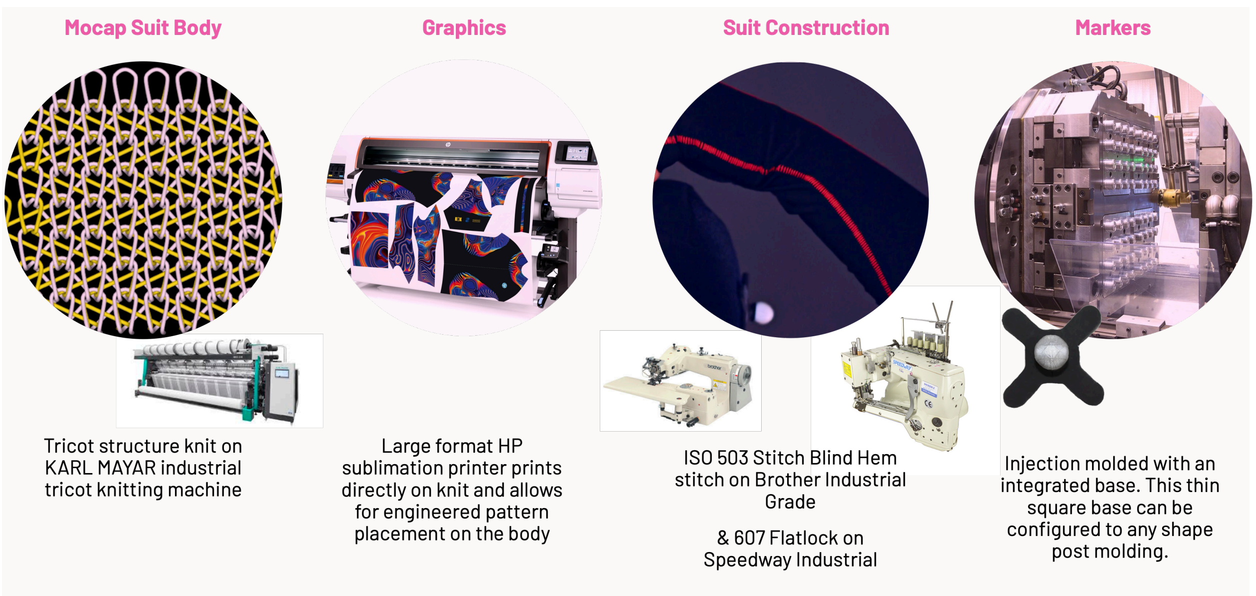


Figure 17 Standard competitor product construction.

Graphic directions on these products are widely sublimation print post fabric construction. Makers using injection molding and Velcro have been standard across multiple types of suits and interfaces and have largely not seen change in the last decade (Glaeser, et al. 2018). Assessment of these methods have left recognized opportunity for improvement in seamless integration. Explorations into more functional integrated graphics, yarn plating and specified areas of garment tension to reduce movement of fabric could be useful.

Utility patent landscape

The utility patent landscape has proven to be one that is difficult to navigate. There are a lot of players in this space, many of whom are creating concepts for technology they don't know how they will use yet. It is critical to the success and longevity of the thesis project that the project space is clear of direct competitors who have funding and resources and recourses not available to this project. Several prior art examples exist in the space of fully integrating piezoelectric technology for real time joint movement analysis as seen in *Figure 18 and 19* below.

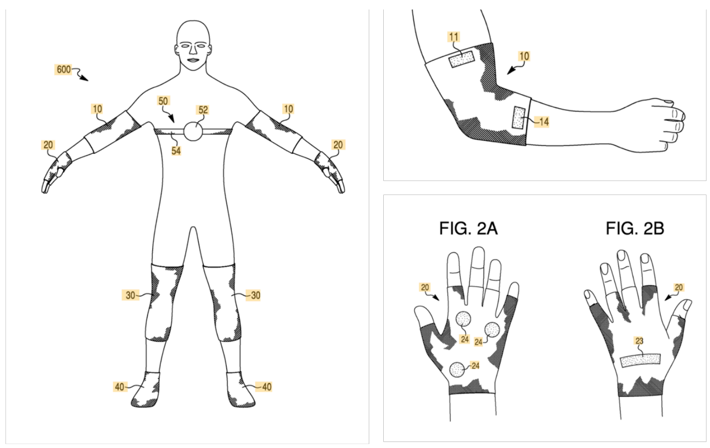


Figure 18 US20160338621A1, Devices for measuring human gait and related methods of use.

"A portable multi-component measurement and analysis device -feedback may be provided in real time on the bio-mechanical and gait parameters experienced by the user's body while performing any particular activity". (US20160338621A1, *Devices for measuring human gait and related methods of use*).

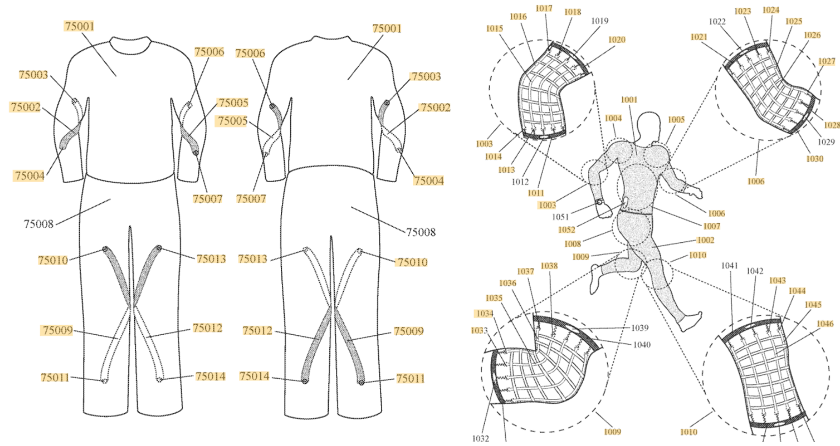


Figure 19 US10321873B2, Smart clothing for ambulatory human motion capture.

“Ambulatory mocap: an article of clothing; electromagnetic energy emitter/receiver; a helical stretching electromagnetic energy pathway. Motion of the body joint stretches and/or bends the pathway, and wherein stretching and/or bending of the pathway changes the flow of electromagnetic energy from the emitter to the receiver; and a data processor to analyzes changes in the flow & measure motion of the body joint.” (US10321873B2, *Smart clothing for ambulatory human motion capture*)

While these technologies are outside of the realm of accessibility that this thesis is aiming towards obtaining, this is the future of state of the real time motion capture that is critical to be aware of. Prior art was not found for apparel that aims to work with existing technology, whether it be optical or non- optical oriented. This is a positive finding, in helping to identify a true opportunity to create product to aid in the accuracy of accessible technology.

Graphic Direction

Color and graphics in the mocap space has been primarily driven by function, with little attention to trend or perceived aesthetics. Progression of color and graphics used in mocap suits through the film and digital asset industry is displayed in *Figure 20*.

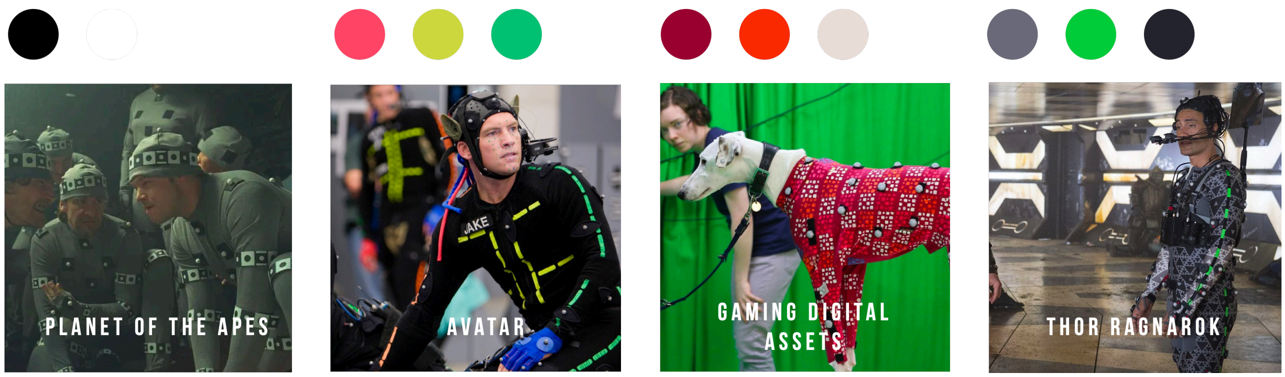


Figure 20 Graphics and colors used for enhanced motion and volume capture in the film industry.

Initial graphics used black and white square rings that allowed animators to manually match up squares to the form in post processing. Avatar, one of the most advanced CGI animation films of its decade explored removing some of this manual process through image processing of RGB to locate correct sides of the body (Sarto, 2019). In the last 6 years more complex geometries have been implemented and is often combined with RGB markers (Sarto, 2019). A generative triangular repeat pattern is currently used as state-of-the-art mocap suits and has decreased editing time and allowed for real time 3D form monitoring while filming (Sarto, 2019). As part of the project scope, the intent is to explore different pattern options, analyze why RGB, and triangular geometries have made improvements to assess where it can be pushed farther.

Strengths, Weaknesses, Opportunities & Threats

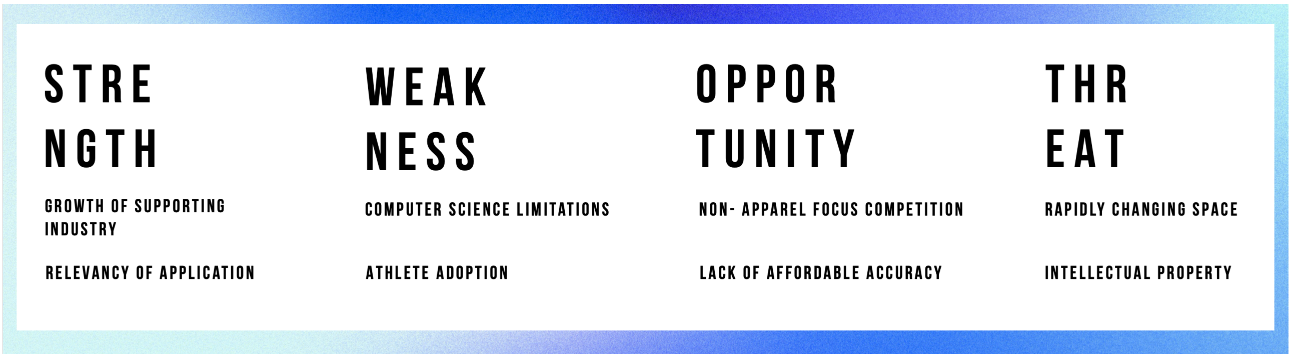


Figure 21 Overview of strengths, weaknesses, opportunities & threats in mocap industry

Selection of the thesis project topic was influenced by trends in the industry and opportunities that were recognized. In assessing the strengths of the motion capture market there were two leading factors identified in *Figure 21*. The growth of supporting industries, outside of sport motion research and training is contributing significant capital to funding the development of technology in this space (Rydén, 2019). Several examples include the movie/ film industry, animation, gaming, and virtual reality. The video gaming industry alone spends millions of dollars on creation of digital assets, many of which start at the motion capture/scanning phase (Rydén, 2019). A second contributing factor in mocap apparel is the relevancy of application. While Mocap has been utilized in biomechanics research there is the opportunity to bridge this technology to an everyday user. Someone without a science degree, or large capital who wants to monitor form with relative accuracy compared to what is on the market. The opportunity to expand mocap to a new consumer is a strong direction to lead in.

While there is confidence in the strength of the industry and growth it is critical to draw attention to weaknesses in the field. No matter how many promising ideas exist, there are still limitations in place based on where technology is at. Within the scope of the project, I understand areas of weakness will exist in personal understanding of computer science principles. The ability for the apparel designed will be reliant on working seamlessly with existing technology, or getting technology codded and developed. This poses a significant threat to the ability to prove concept and will be monitored consistently. A second point to address is the athlete adoption rate. While the purpose of the product exploration it to make accurate motion capture more accessible, there is still risk associated with user experienced (Adapa, et al. 2018). Getting the intended user to purchase and wear the product is only a small portion of the hurdle when compared to getting easy to use and interpret data. Integration on the user end will be a consideration as the project progresses through the ideation and design process.

Opportunity exists in the motion capture apparel space due to the current player's strengths and lack of options. Upon examaning many of competitor products and companies, it was found that they have been primarily founded by a computer engineering team (Colyer, et al. 2018). What was not observed was a strong foundational idea that sparked from a technical apparel minded individual. It is seen in mocap suits that there is very little innovation and functional design elements implemented. The secondary importance placed on the apparel, with the focus being on the camera technology surrounding leaves immense space for improvement. By taking an approach focused on the apparel aiding in technology, not the other way around, the barrier to obtainability could be reduced. Currently accurate options will run the user over $20,000 USD (*Vantage: Cutting Edge Flagship Camera by Vicon*, 2020). Even at this price range it takes an experienced user who understands a program to gather the 3D forms and extract useable data.

Two clearly identified threats to the project space have been identified through the research. First, this is a rapidly changing product space. What is capable with technology is constantly changing, this creates issues of quick product obsoletion. Through my R&D process it will be necessary to be aware of what is up and coming to design for the longest lasting product possible. One factor that complicated this process that has been identified as a secondary threat in *Figure 21* is the amount of work in this space that is under utility patent and may not be public access. There is a level of risk working in a space knowing companies are also exploring similar concepts simultaneously. As a student project direction however, this is a strong place for it to be to display the understanding relevancy of the topic area.

Project Scope & Alignment

With an undergraduate degree focused in apparel, I came into the program with the hope of exploring footwear and diversifying my skills. Through the course of doing so I found that my interests really remained in the apparel field. However, my eyes were opened to the variety of technology and innovative principles that existed in this space. Additionally, I noticed areas where innovation was lacking, and left room for improvement. My strengths lie in pushing technology in the apparel workflow and I wanted to have this concept be at the forefront of my thesis topic. The exploration of motion capture apparel is related directly to how apparel can work as a tool to support technology. Through product innovation in the last 15 years, these roles have primarily been flipped in that technology has been a tool to support apparel creation.

I have a strong background in 3D apparel creation and have been using it as a tool in my design process since undergrad. I have since built upon this skill by learning how to use a 3D body scanner and analyze body measurements to accuracy levels of 1mm. (*3D Object Scanner Artec Eva*). My experiences in these areas have helped keep me up to date on state of art workflows. Having an innovative design process that allows for iteration based on data is key to the type of work I want to be doing, and I now have the skills to do so. This project for me is a natural progression on my interests in the 3D space and incorporating movement. I have a strong foundation with technical fabrics and will be utilizing my understands of textiles to propose innovative solutions. Many teams working in the motion capture space are started from a tech background, rather than having foundational apparel be the heart of the project. Because of this, I will have a unique approach to solving problems in this space that puts the focus on the apparel and its relationship to the moving body and cameras capturing it.

My goal in pursing this thesis pathway is to reiterate my ability to execute aesthetic, technical sports apparel and prove my ability to push the industry and think outside of the box. In my body of work up to date, I have several strong apparel design projects with solid research. However, I do not feel I have projects that would be able to speak to tech or innovation positions. The intent is to position myself for a variety of apparel applications that may be outside of what a traditional apparel inline product job would look like. This project deeply integrates an understanding of wearable/ technology as related to body motion capture. This forces me to look outside of the apparel industry for interdisciplinary expertise. This is the same kind of team dynamic I could expect in an innovation or technology role. The project will challenge me to work with ambiguity, and a non-linear process to the solution as I try different validation methods.

While one year ago the possibilities of where I saw myself felt very narrow, this is no longer the case. Job pathways that I am seeking out post-graduation range. These include, but are not limited to: Wearables (medical, sport applications), Sport apparel innovation/ material innovation

(Nike, Under Armour), tech companies (Google, Facebook, Microsoft), technical outerwear (Snow peak, North Face), Women's apparel (Athleta). By focusing on how apparel can seamlessly integrate with both a moving body and technology my portfolio will become stronger for these desired roles.

Mentor Mapping

Phase 2

Testing & Ideation

Introduction

After identifying a clear gap in the market, it was critical to begin to assess what the project wants to be obtaining and how it will be executed. Through phase 2 of the project, a detailed breakdown of what current options is will be provided along with the strengths and weaknesses to help define opportunity. From there primary testing will be conducted to gather baseline and user information. This will allow for a final path to take for Apture Apparel to have the biggest impact on the product space and user performance. Ideation will commence i

Detailed SWOT Analysis

Benchmark product

Figure 24 Optitrack Motion Capture Suit

Optitrack Motion Capture Suit

Sizing: Alpha S-XL Unisex fit
Price: $289 USD
Material: 90 Nylon 10 Spandex Blend Tricot Knit. Anti-microbial finish

Features:

- Elastic Waist Band for secured fit
- Antimicrobial
- Highly breathable
- Exceptional freedom of movement and comfort over long recording sessions
- Included Velcro cap
- Velcro attachment to shoes
- Compatible with Optitrack x-markers making them near impossible to knock off

Components

Knit Onsie
Closure/ entrance method
Securement to keep suit in place (Velcro straps) *(Motion capture suits, n.d)*

Areas for Improvement

[Aesthetic] sportswear can be worn reasonable outside of a lab environment
[Visual Joint Recognition] for manual video analysis
[Secured Fit/ Positioning] around joints to remain in place facilitating accuracy

SWOT

Aesthetic

	Knit Body	Closure/ Entrance Method	Securement to keep suit in place
Strengths	High content of spandex allows for great mobility. Simple silhouette, single piece garment helps pieces not get lost, creates a one and done option for motion tracking.	Method to get in and out is intuitive, durable easy to use. Zipper is Low profile.	Thumb loops is pretty standard in the athletic industry, effectively keeps the sleeves from riding up. Velcro loops that hook under the shoes function to keep the pants from riding up with a low profile.
Weaknesses	Unisex fit does not provide a universal solution, size chart leaves a lot of room for question as to what sizes individuals should buy which leads to unflattering fits. The Onesie silhouette is not a style that would be widely worn during sport practice outside of a lab environment. Materials + seams are not very technologically advanced. Does not offer any abilities to enhance markerless motion capture.	Zipper feels old school. CF placement becomes and eye sore. Mobility/comfort could be an issue as the individual's torso bends over.	Velcro loops are a rudimentary option to keep the pant legs down. Do not visually communicate sport, performance, fashion which are all important qualities to the user. The Velcro under the foot would not work for true sport performance as it would inhibit functionality of the footwear.

	Patterning visually indicates menswear despite being unisex.		
Opportunities	Applying activewear trend concepts will improve the wearability of the garment. Current design offers no solution to markerless motion capture technology development, or any uses with accessible mocap aps. Taking these into consideration moving forward creates a wide-open market space.	Straying from the traditional one piece creates opportunities to use multiple garments, eliminating long bulky zippers.	Opportunities exist to explore integrated solutions to keep the suit in place with the design of the main body/ more specific fit that would create a more seamless aesthetic
Threats	Moving away from a one piece- unisex body construction creates a need for a non-unisex fit, more sizes/skews.	Taking away a onesie approach with long zippered entrance may disturb the expectation of motion capture apparel, may not communicate that is it mocap apparel.	A more complicated solution would not be a one and done solution. Iteration and testing would need to be done.

Visual Joint Recognition

	Knit Body	Closure/ Entrance Method	Securement to keep suit in place
Strengths	Velcro offers options for attaching separate markers at joint locations	Closure method does not directly inhibit visual joint recognition.	Securement method does not directly inhibit visual joint recognition.
Weaknesses	This solution is intended for optical motion capture- not a markerless option which is where the industry is heading and trying to achieve. Manual placement of markers repeatedly lends room for human error. Could be hard to determine accurate joint location through the mocap suit. This solution is not	Closure method does not facilitate visual joint recognition.	Securement method does not facilitate visual joint recognition.

	feasible to wear during sport.		
Opportunities	Create graphics already integrated into the body of the fabric at joint locations that a person or computer program can easily recognize that doesn't involve Velcro markers	Eliminating intrusive closure methods create opportunity to have marking/ graphics/ functionality there that area was originally being occupied.	Eliminating intrusive securement (i.e Velcro loops) methods create opportunity to have marking/ graphics/ functionality there that area was originally being occupied. Thumb loops have opportunity to have graphic call out to wrist location.
Threats	Graphics need to be visually appealing yet clearly indicate specific joint location from serval potential filming angles which proposes a design problem to solve	Having no closure method requires knit- this lends potential issue to graphic disruption if knit garments are stretched without recovery overtime- will need to be tested and addressed.	Having no Velcro loops for the securement method requires knit- this lends potential issue to graphic disruption if knit garments are stretched without recovery overtime- will need to be tested and addressed.

Secured Fit/ Positioning

	Knit Body	Closure/ Entrance Method	Securement to keep suit in place
Strengths	Spandex knit offers a forgiving fit for multiple variations of body types with in a single alpha size.	Closure method allows the garment to be one piece and form fitting.	Securement method ensures the garment is covering the ankle and wrist joints.
Weaknesses	Single knit structure creates only one level of tension/compression that is not unique to the shape of the body/ joint at that location.	Closure method does not directly facilitate secured fit to retain joint positioning over anatomical joint locations. Zipper only allows the garment to not fall off of the body but does not keep the garment from moving independently to the body.	Securement method does minimal to retain joint positioning over anatomical joint locations. Velcro loops and finger holes only keep the garment limbs from sliding up but does not keep the garment from moving independently to the body in middle

			locations of extremities.
Opportunities	Creating engineered tension/ shaping and multiple levels of elongation/ linearity within the knit structure can allow for a more precise fit.	Eliminating closure needs create more flexibility in knit structures using circular knitting.	Utilizing a knit structure with higher elongation between secured knit structures at the joint location can help isolate these areas and retain accuracy despite discrepancies in sizes of individuals.
Threats	Creates a more expensive/ solution with potential durability issues that would need to be addressed.	Ease of entry of garment with higher structured/ tension areas would need to be addressed.	Accounting for the differences in distances between joint locations/ distances between individuals.

After assessing the features of the state-of-the-art motion capture suit it became clear that the garment construction and materials were overlooked in the development process and that it is not a garment that would function for an athlete outside of a clinic environment. This reaffirms the opportunity for a garment that is not limited to a high end indoor testing environment and does not inhibit athlete performance.

Testing Plans

A. Introduction and Background

Form is a critical part of athlete success in a given sport activity. Elite athletes around the world utilize state of art research labs to record data, perfect form and optimize performance. An opportunity lies in bringing rudimentary forms of this technology to younger athletes to begin to implement into their training. During high school, athletes' bodies are changing rapidly, and it takes time for them to develop high awareness for their bodies positioning. For individuals hoping to go to the next level with their sport utilizing visualization tools to assess their form can make a critical difference in making it to collegiate level or not. When it comes to understanding of biomechanics, and funding to acquire technology to utilizing state of art motion capture technology is no longer a feasible goal. Understanding how to utilize existing programming in entry level product obtainable to this market will be key to a successful product.

Part 1: Anthropometric Data Collection

B. Specific Aims/Study Objectives

The aims/objectives for the proposed study, include to understand:

- What is the standard variation of distances between major joint/ bone marker locations for a set of individuals that wear the same alpha size sports garments? This will inform assessment of how to ensure visual markings end up over the correct area of the body regardless of body proportion variation within one size.
- What are the circumferences around the joint anchoring locations? This will give a baseline for creating averages of sizing and helping to assess proper amount of compression.
- What are the circumferences parallel to the joint circumference on either side of the joint? This will inform differences in sizing that can help secure this section of the garment around the joint.
- What are the major circumference body measures? This will be compared to the sizing chart to ensure they fit within the alpha sizing. (Refer to figure 25 for points of measure)

C. Methods, Materials and Analysis
METHODOLOGY

Subjects of Study: Subjects of study were chosen from a base scan set based off of their bust waist and hip measurements fitting within the sample size range. Anonymity of subjects will be maintained through presentation of findings.

Timing: The study does not require timing of external space or subjects and will be done on the researcher's time alone.

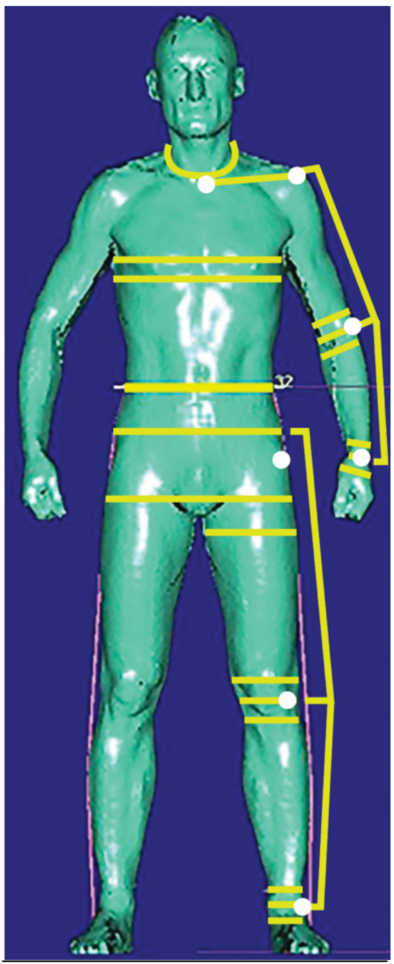


Figure 25 Anthroscan Measures Diagram

Phase of Study	**Procedure**	**Data Collected**	**Timing**
Subject Selection	Open up scans from files and take initial planar measurements of Bust, Waist Hip to compare to size charts	NONE	NA
Data Collection (Researcher working in Anthroscan)	Run Automatic Measurements in Antroscan to gather Height, base distance information	Subject Height – Recorded in Excel	NA
	Using the Plane feature create planes at the subjects Bust then pull the measurement from cut plane using the tape measure style measurement.	Bust Circumference- Recorded in Excel	NA
	Repeat with under bust, waist, high hip, hip, thigh 1’’ below crotch.	Under bust, waist, high hip, hip, thigh 1’’ below crotch circumference – Recorded in Excel	NA
	Use marker feature and mark CF of the body at the collar bone.	None	NA
	Repeat marker tool with outer patella, outer ankle, outer hip crease, center elbow, wrist joint, (acromion) shoulder bone.	None	NA
	Take distance measurements contouring along body according to diagram above: ankle to knee, knee to hip crease. Wrist to elbow, elbow to acromion, acromion to CF.	Joint distance measurements x 5 – Recorded in Excel	NA
	Repeat with 20 Males and 20 Female subjects	All of the above x 40 – Recorded in Excel	NA
Post Data Collection	After tracking all data in excel, look through numbers and identify any large outliers that do not reasonably make sense with	None	NA

	the subject re-measure that subject. Otherwise toss the number before calculating findings.		

Data will be saved to a disk along the data collection process.

MATERIALS REQUIRED

Due to using previous scan files, space, garment, and equipment needs have been minimized.

1. Anthroscan Program+ PC computer compatible with Anthroscan

Part 2: Video Tracking

D. Specific Aims/Study Objectives

The aims/objectives for the proposed study, include to understand:

- What is the baseline amount of angle slippage the program experiences? This will create a benchmark for me compare alternative options to.
- How does slippage of different geometrical patterns compare to one another?
- How does slippage of different organic patterns compare to one another?
- How does slippage of localized pattern placement vs full leg placement compare to one another?

E. Methods, Materials and Analysis

METHODOLOGY

Subjects of Study: One subject will be used for all of the trials for efficiency and to remove variables of individual mechanics and body shape. Subject will be provided test leggings, base tank top, but will wear their own preferred undergarments.

Timing: The study should take course over 2 days to allow for sufficient rest time between sessions so that fatigue is not a factor in the repetitions.

Phase of Study	Procedure	Data Collected	Timing
Subject Recruitment	Ask individual to participate in study	NONE	NA
Workspace prep	Prepare open space with solid color bottom and back drop. Apply tape where the subject should put their feet, set up camera and tripod.	None	Prior to subject arriving
Data Collection (Subject is at the workspace)	Subject gets briefed on what they need to do (what the repeated motion is, how to stand, how it will be captured)	Subject Height, Waist, Hip Measurement- recorded in excel.	5 minutes
	Subject Changes into legging condition 1 (wears black tank top)	None	3 minutes
Data Collection (Subject is at the workspace)	Subject stands on dots on the floor and competes 25 squat repetitions at a consistent pace with condition 1.	Video is captured	1 minutes
	Subject changes into legging condition 2	None	3 minutes
	Subject stands on dots on the floor and competes 25 squat repetitions at a consistent pace with condition 2.	Video is captured	1 minutes
	Subject changes into legging condition 3	None	3 Minutes
	Subject stands on dots on the floor and competes 25 squat repetitions at a consistent pace with condition 3.	Video is captured	1 minutes
	Stretch- break	None	10 Minutes
	Subject changes into legging condition 4	None	3 minutes
	Subject stands on dots on the floor and competes 25 squat repetitions at a consistent pace with condition 4.	Video Is captured	1 minutes

	Subject changes into legging condition 5	None	3 minutes
	Subject stands on dots on the floor and competes 25 squat repetitions at a consistent pace with condition 5.	Video is captured	1 minutes
	Day 1 Conclusion	None	Total: 40 Min
Data Collection (Subject is at the workspace)	Day 2	None	NA
	Subject changes into legging condition 6	None	3 min
	Subject stands on dots on the floor and competes 25 squat repetitions at a consistent pace with condition 6.	Video is captured	1 min
	Subject changes into legging condition 7	None	3 min
	Subject stands on dots on the floor and competes 25 squat repetitions at a consistent pace with condition 7.	Video is captured	1 min
	Subject changes into legging condition 8	None	3 min
	Subject stands on dots on the floor and competes 25 squat repetitions at a consistent pace with condition 8.	Video is captured	1min
	Stretch- break	None	10 min
	Subject changes into legging condition 9	None	3 min
	Subject stands on dots on the floor and competes 25 squat repetitions at a consistent pace with condition 9.	Video is captured	1 min
	Subject changes into legging condition 10	None	3 min
	Subject stands on dots on the floor and competes 25	Video is captured	1 min

	squat repetitions at a consistent pace with condition 10.		
End of Data Collection Session	Subject changes back into original clothes, is thanked.	None	5 min
	Day 2 Conclusion	None	45 min
Post Data Collection (done by researcher separately of subject)	Video taken into Dartfish video tracking software on MAC. Ankle, knee and hip crease is marked in dartfish and automatic angle tracking is ran through the 25 repetitions	The number of repetition where any slippage off of the original assigned locations is first observed will be recoded. The magnitude of slippage off of the original assigned locations at end of 25 repetitions will be recorded.	NA
	Repeat will 10 legging conditions	The number of repetition where any slippage off of the original assigned locations is first observed will be recoded. The magnitude of slippage off of the original assigned locations at end of 25 repetitions will be recorded. X10	NA
End Analysis	Compare findings to assess any patterns of graphics creating more accurate image processing following within the program.	None	NA

Data will be saved to a disk along the data collection process. All apparel provided to the subject, will be professionally laundered prior to wearing.

MATERIALS REQUIRED

Video tracking exploration will include space, apparel and technology requirements but will not require multiple subjects

1. Dartfish Program+ PC or Mac computer compatible with Dartfish
2. Baseline shorts+ tank garment
3. White floor cover + backdrop
4. Changing space
5. Black tank top

6. 10 Black athletic leggings
7. White Legging
8. White sport heat vinyl
9. Black sport heat vinyl
10. Circuit Cutter machine
11. Smart phone with high-speed video capabilities
12. Smartphone Stand

Testing Results

Baseline Video Tracking Trials

Apture Apparel aims to create a new product opportunity and category. Because of this, sourcing true competitor products to baseline was difficult. Rather, testing went in a direction of trying to understand the image processing algorithms of existing app technology. As described in Part 2 Video Tracking Testing Plans, 10 legging patterns were created displayed in *Figure 26*.

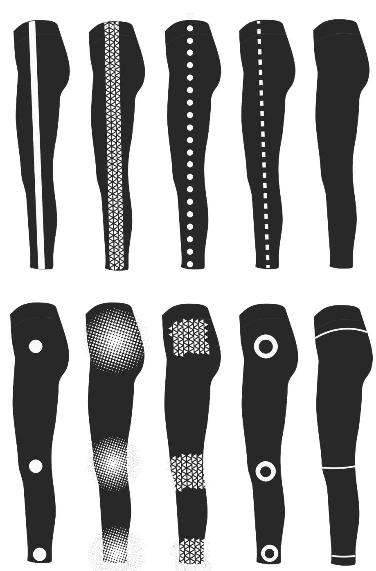


Figure 26 Initial Pattern Prototype Exploration

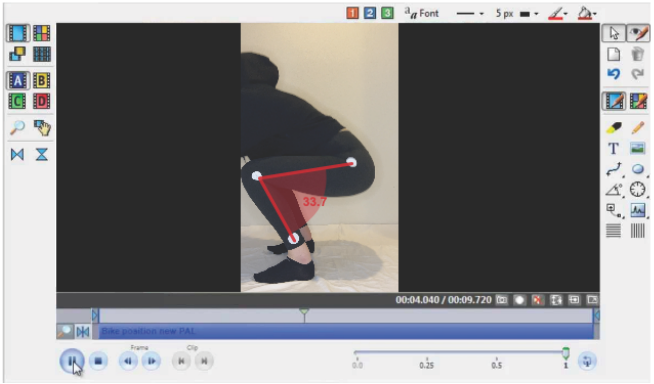


Figure 27 Joint Angle Tracking in Dartfish

The process to collect data utilized Dartfish motion app utilizing an automatic tracking tool. Videos of the static squat in the pattern variations were uploaded and ran as shown in *Figure 27*. The slippage of angle measure from the original assigned location was measured using a grid overlay and results are displayed in *Figure 28*.

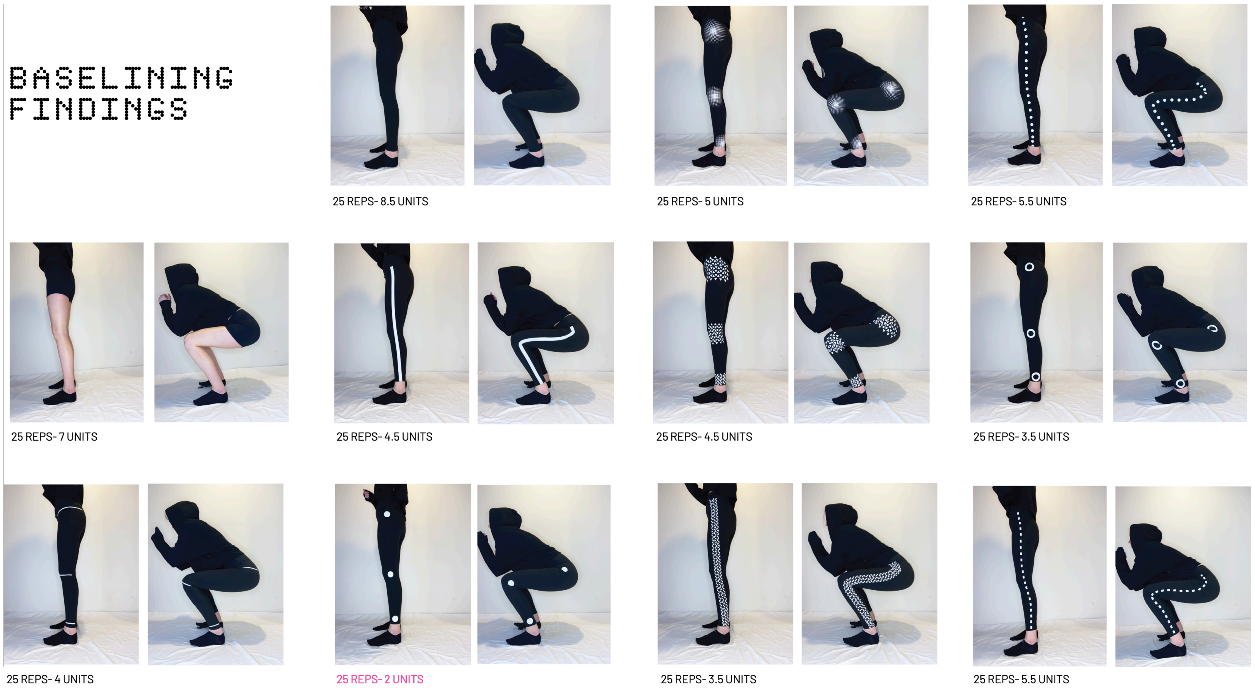


Figure 28 Joint Angle Slippage Results

After conducting the trials, it was found that the most concentrated area of contrast, shown in the pink labeling, resulted in the least amount of slippage at 2 units (*Figure 28*). All graphics did result in slight improvements when compared to the shorts baseline.

User Qualitative Survey

Through reaching out to contacts in high school as well as high school coaches 22 athlete responses and 5 coach responses were recorded. Within these responses the sports of the athletes/ coaches varied across basketball, soccer, track & field, softball and volleyball. This created a diverse group to cover many different styles of coaching, needed form analysis and base practice brands. An overview of high-level results is displayed in *Figure 29*.

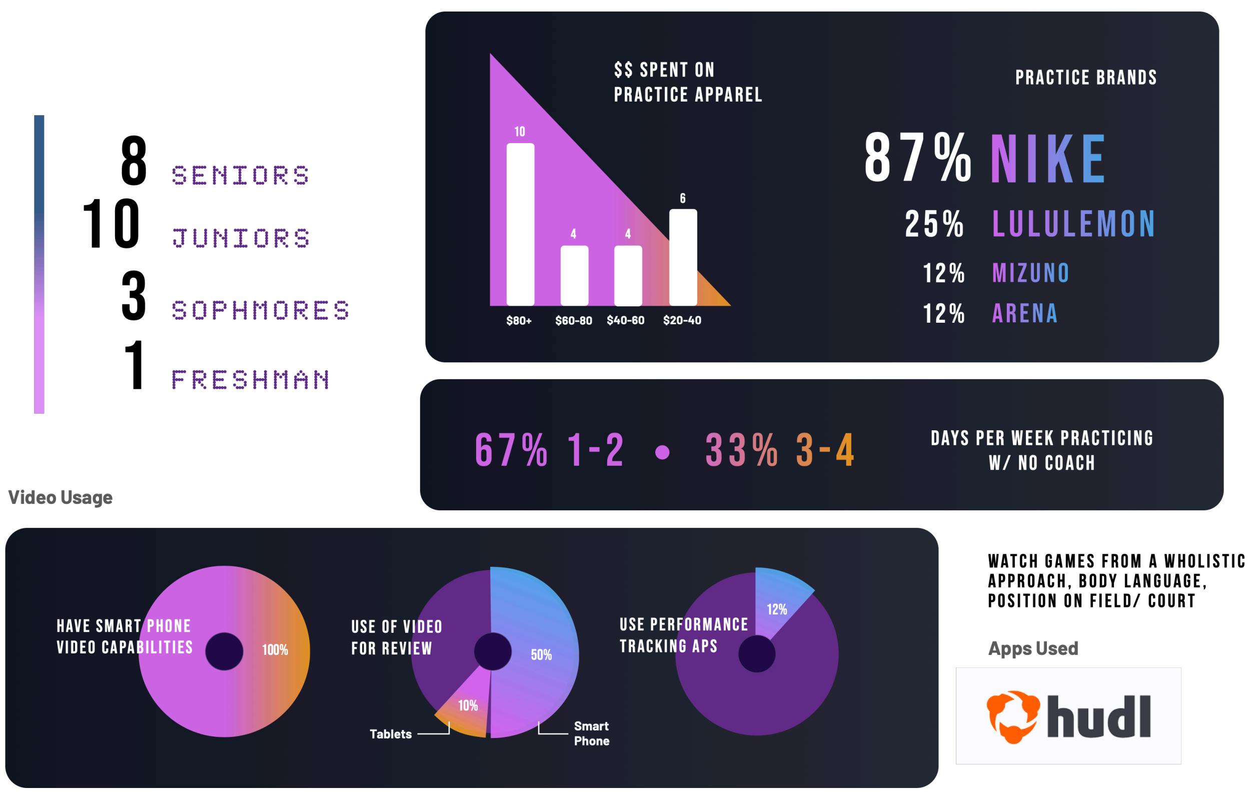


Figure 29 Infographic of Target Market Survey Results

Found results from the surveys indicate several things. First, it was important to note what athletes are currently spending on athletic practice apparel. Because Apture Apparel aims to be in the accessible range this garment should provide a new benefit to the user, but cost in the same range as other practice apparel. It was found that the majority of students were spending $80 on their pieces and buying primarily Nike. This information informed the next study in how I selected the body scans to measure. A reassuring finding through this collection was the frequency of which individuals were practicing without coach or mentor present. 33% of survey respondents were practicing over half of the week with no coach present. 100 percent of the respondents were limited in technology to smart phone capabilities (*Figure 29*). It became clear that the opportunity for Apture Apparel is assisting an autonomous baselining and assessment utilizing video they can take on their phone.

Anthropometric Data Collection

Through gathering data from 20 female and 20 male body scans average data of the circumferences and distances of major joints were collected. As displayed in *Figure 29* the process involved a series of planer cross sections and marked points.

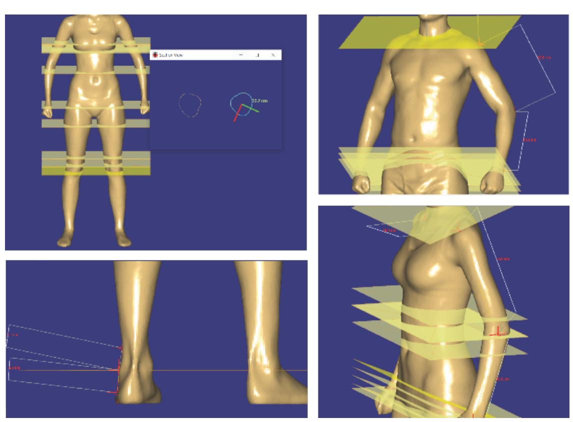


Figure 30 Images From Anthroscan of Process

After recording in an excel spreadsheet outliers in the data were removed and the measures averaged. Results are shown in *Figure 31*.

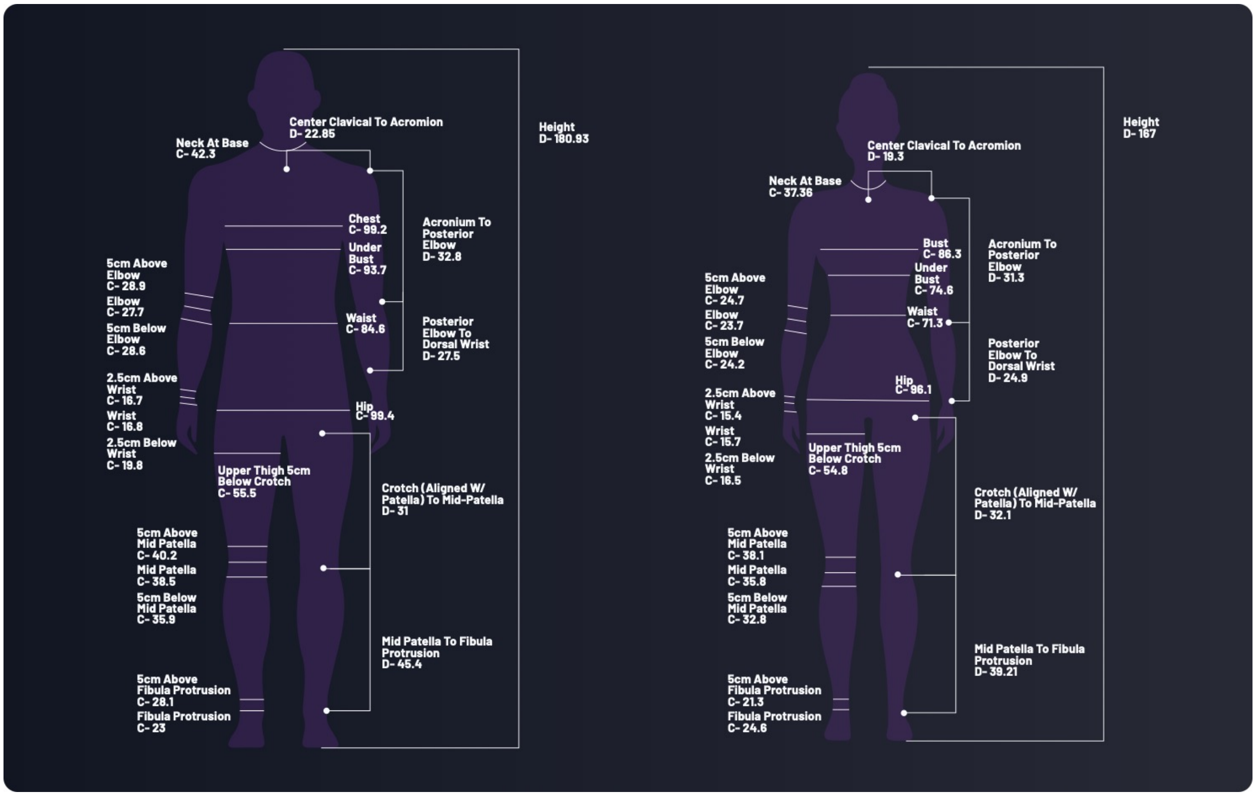


Figure 31 Diagram of Anthroscan Averaged Data

Points of measure labeled with "C" are measures of circumference whereas measures labeled with "D" are measures od distance between two points (*Figure 31*). The purpose behind this study is for fit, as the athlete's body is in motion the garment needs to have a secure fit. Due to the nature of the product, graphically calling out joint locations it is critical that the garment does not move independently of the body. This unwanted shifting of the garment could compromise the accuracy and visual ques it is intended to provide.

Interviews

Apture Apparel is aiming to combine sports apparel with entry level biomechanics and image processing. Due to this it is important to understand gaps in expertise and reaching out to experts to get feedback and validation. Through phase 2 gathering feedback and insights from industry professionals in fields outside of apparel was needed to validate the use and the visual biomechanics markings.

ERIC SORENSON

Department Chair Kineseology Azusa Pacific University

" I love the ideas! The mark locations look good.. You are on the right track with this product."

SHANNON POMEROY

Design Research & Data Specialist Apple

"I don't think your success is rooted in just those scenarios you laid out.. its about creating a general body awareness"

EMILY KAROLIDIS

University of Oregon P.H.D Biomechanics & Sports Product Design Student

"You're translating between the technical science and the everyday user... this is relevant to them because it is something they can understand"

Figure 32 Profiles and Quotes of Field Experts

Feedback listed in *Figure 32* helped to define the opportunity for Apture Apparel. Eric Sorensen, the department chair of Kinesiology provided insights on marking locations for the body. Helpful feedback involved pushing me to consider multiple angles of markers and visibility from different planes. Another consideration that was pointed out through this conversation was the level of rotation of upper limbs and the need for potential connection points of the dots for a level of visibility form a variety of perspectives. Conversations with Shannon Pomeroy and Emily Karolidis helped define opportunities for my direction in creating a bridge between the every-day user and biomechanical clinical science. One exciting door Apture Apparel is opening is the ability to take form feedback to the outdoors as clinical studies are limited to where their cameras can take them.

Product Brief

Moving towards ideation two clear goals were set for the Apture Apparel line. First, provide a visual indication of what's going on to an everyday user to help inform productive conversations with coaches and trainers. Secondly, integrate with rudimentary video performance apps/iPhone camera to capture the body without being limited by expensive cameras or indoor environments. These two goals will be my basis for success come the end of the project. Due to limited time the line will feature these for products initially for testing purposes.

1. Women's Tight
    a. Seamless Engineered Circular Knit Leg x 2
    b. Knit Waist band
    c. During/Post knit graphics application/ dye finishing
2. Women's Long Sleeve Top
    a. Seamless Engineered Circular Knit Sleeve x 2 + Bodice
    b. During/Post knit graphics application/ dye finishing
3. Men's Arm Sleeve
    a. Yarn- Unknown
    b. 1 Engineered Circular Knit Sleeve
    c. During/Post knit graphics application/ dye finishing
4. Men's Tight
    a. Yarn/ Yarns
    b. Knit Waist band
    c. During/Post knit graphics application/ dye finishing

Ideation

Material

Materials for the product need to function at the level of the users preferred practice apparel. This is because the product should not be inhibiting performance or causing any sort of discomfort for the athlete.

	Performance Goals	Material That Will Solve This	Ideas on Where to Source	Action Items (Complete between 01/29-02-03)
Compression Knit- Anchor	Provide secure area of the garment locked around the joint. Breathable, high stretch & recovery, moisture wicking. (susceptible to spikes/ snagging/ friction on court or turf) (Wash durability) (Indoor+ Outdoor conditions)	Ideal: -Polyester -Nylon -Lycra -Circular Rib knit with varied knit densities (made holistically on circular knitting machine) -Rib Knit by the Yard -Bemus	Ideal: Shima Seiki Eva X Carola BYBORRE -Mill End -Rain Shed -Spandex By the Yard -Debs -Fabric.com -Personal stores of extra Browzwear client fabrics -Cricut Heat transfer Vinyl (stretch or non-stretch will have to be tested)	Research how much a knit programmer runs per hour. Email Carola. Email Borre Connect with Jessie about Shima Seiki/ development process Connect with Stephanie about minimum fabric quantify order for certain suppliers.
Main Body Knit- Between locked down zones High elongation	High elongation provides plenty of stretch to allow joint areas to account for variations in distance between joints. Breathable, high stretch & recovery, moisture wicking. (susceptible to spikes/ snagging/ friction on court or turf) (Wash durability) (Indoor+ Outdoor conditions)	Ideal: -Polyester -Nylon -Lycra -Engineered Raschel Knit (made holistically on circular knitting machine) -Non-Engineered Poly Spandex Sport Raschel Knit.	Ideal: Shima Seiki Eva X Carola BYBORRE -Mill End -Rain Shed -Spandex By the Yard -Debs -Fabric.com -Personal stores of extra Browzwear client fabrics	Research how much a knit programmer runs per hour. Email Carola. Email Borre. Connect with Jessie about Shima Seiki/ development process Connect with Stephanie about minimum fabric quantify order for certain suppliers.

Knit Waist Band	Low profile, stays in place, may differ for men's and women's style. Breathable, high stretch & recovery, moisture wicking. (susceptible to spikes/ snagging/ friction on court or turf) (Wash durability) (Indoor+ Outdoor conditions)	-Polyester -Nylon -Lycra - Rib knit- or Interlock Knit. - Mesh/reinforcement/Middle layers	-Mill End -Rain Shed -Spandex By the Yard -Debs -Fabric.com -Personal stores of extra Browzwear client fabrics	None.
Band/ Material	Keeps sleeve/ leg in place from riding up or falling down. Does not dig in, cause friction or stop any circulation. Breathable, high stretch & recovery, moisture wicking.	Wide Compressive circular Rib knit. -Polyester -Nylon -Lycra -Circular Rib knit with varied knit densities (made holistically on circular knitting machine) -Rib Knit by the Yard -Polyester -Nylon -Lycra (high content- 20-13%)	-Mill End -Rain Shed -Spandex By the Yard -Debs -Fabric.com -Personal stores of extra Browzwear client fabrics	None.
Possible Interior Texture/ Grip around Joint	Helps keep sections of graphics around joints in place without twisting to improper location. (Placed on the interior) Does not dig in, cause friction or stop any circulation. Does not inhibit breathability, stretch & recovery, moisture wicking.	-Injection molded Silicone- heat application -Double Knit Interior Knit texture -Perforated 1 sided adhesive heat application -3D print flexible material straight onto fabric (Could use elastic with it for time being)	-Amazon -Cando -DIY Mold, Silicone mix make my own and makeshift adhere -Nucleus lab 3D printer -Amazon silicone elastic for mockup purposes	Connect with Stephanie about option/ samples. -Reach out to James about flexible options
Graphics + Color	Creates visual elements for individuals/ programs to easily pick up. Must not inhibit stretch/ breathability of functional performance garment.	Ideal: Integrated graphics through wholistic knit design. Engineered pattern through pre-dyed yarns- Jacquard processes. -Sublimation graphics -Circut sport heat transfer -Combination of the two	- Done through circular knitting -PortlandInk.com Local, can do full coverage sublimation.	Email Carola. Email Borre. Contact Portland Ink to see if they could do full coverage sublimation on knit fabric. See if this would be a pre or post make graphics process for them.

			Alternative: Swag Northwest - Portland Embroidery & Screen Printing Services -Joann's/ Amazon for Cricut sport heat transfer (last choice)	

An inhibiting factor through this stage of the sourcing and material ideation process was the uncertainty surrounding whether or not circular knit will be a viable option. Through networking resources, I met a knit studio based out of the UK Eva X Carola (Eva X CAROLA, n.d.). They work in knit innovation, body mapping, functional and performance knit. An example of their work is shown in *Figure 33* (Eva X CAROLA, n.d.).

Figure 33 Eva x Carola Circular Knit

Eva and Carola partner with Santoni Shanghai Material Experience Center which is the method in which the materials will be produced.

Phase III Design

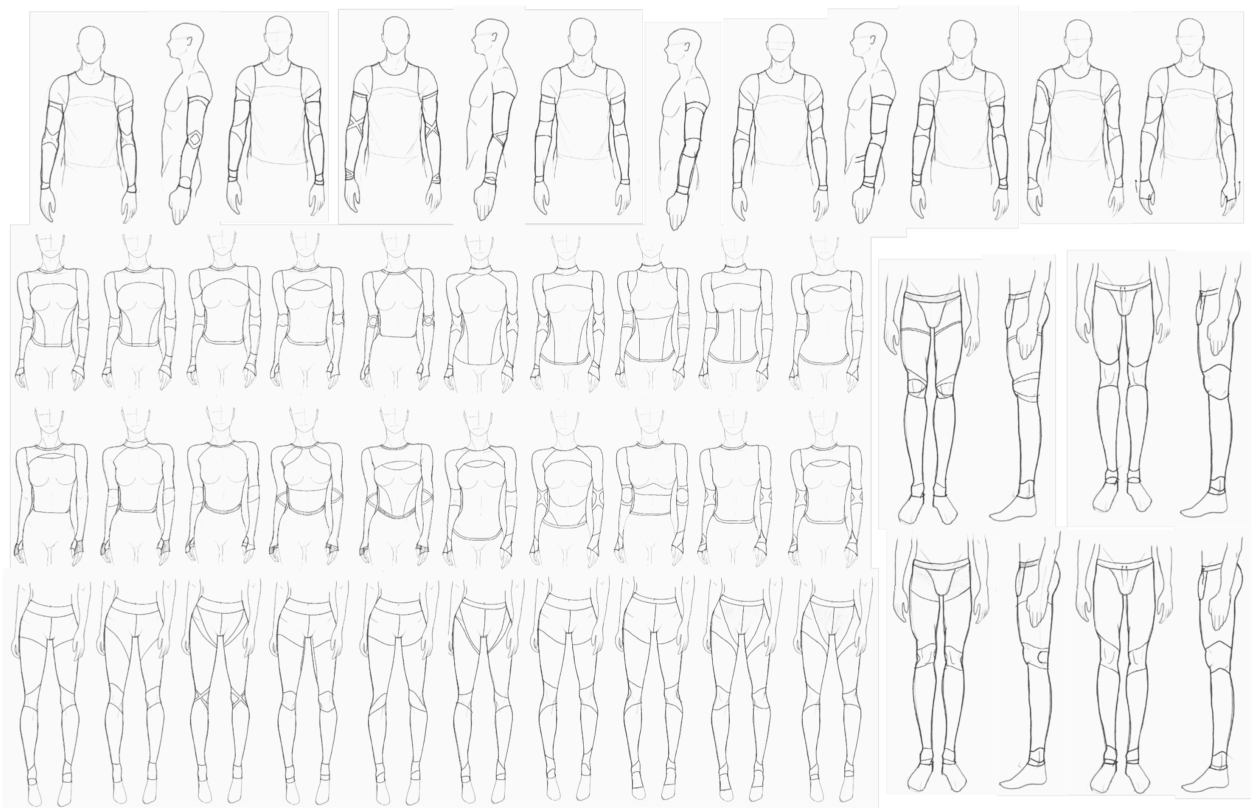


Figure 34 Aesthetic Sketching

Initial ideation shown in *Figure 34* illustrates initial concepting for zoning out the garment and locking system as well as the overall silhouette. The product line will include a women's top, women's legging, men's tight and men's sleeves. Long tight silhouettes allow for the most body coverage to mark the most points on the body, therefor allowing the highest amount of data capture for different movements. In understanding that my target market is high schooler, I was concerned about the early adoption rate of males within this demographic with full tight outfits.

The tights to layer with sleeves allowed for flexibility off dress while still broadening the product range.

Function

Utilizing data collected from the anthropometric study a baseline of the circumferences of joints and average distance, as well as the variance of those distances were able to be computed. It became evident that there would need to be different properties of fabric integrated into the garment to account for reducing the movement of the garment but also the variance in height between individuals of the same alpha size. Ideation of these zoning and features are called out in *Figure 35*.

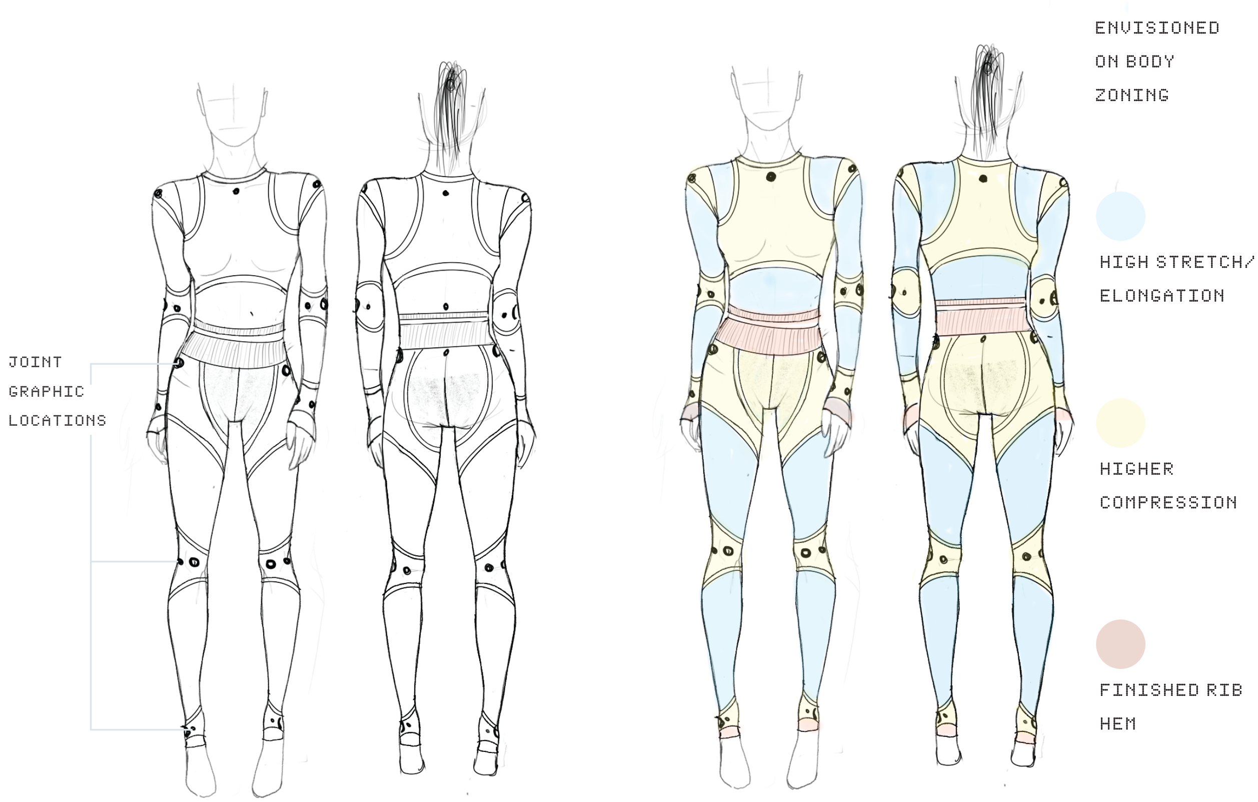


Figure 35 Knit Zone Ideation

The upper left side of the image *Figure 35* depicts the locations of graphical marking as identified through conversations with my expert interviews. This ideation was then overlayed with a color-coding system for knit functionality. The areas around grey surround the joints will be a more compressive knit structure to lock in these areas from shifting. The pink areas of the garments will be a knit structure with higher elongation capabilities allowing the garment stretch to fit longer and shorter limbs.

Graphic

The goal of compatibility with rudimentary camera/ image processing technology and the need to be able to assess a body by naked eye ensured that the color and graphic direction needed to be a core part of the solution. The color pallet for Apture Apparel was created by taking colors from different sporting environments and finding their true complementary colors (*Figure 36*). The reasoning behind this was derived from the video tracking simulation trials in finding that concentrated areas of contrast was the easiest for iPhone video quality trials to pick up and track. Moving forward with the product I wanted to push this concept past black and white and create an integrated solution of contrast to the environments the athletes will be operating in.

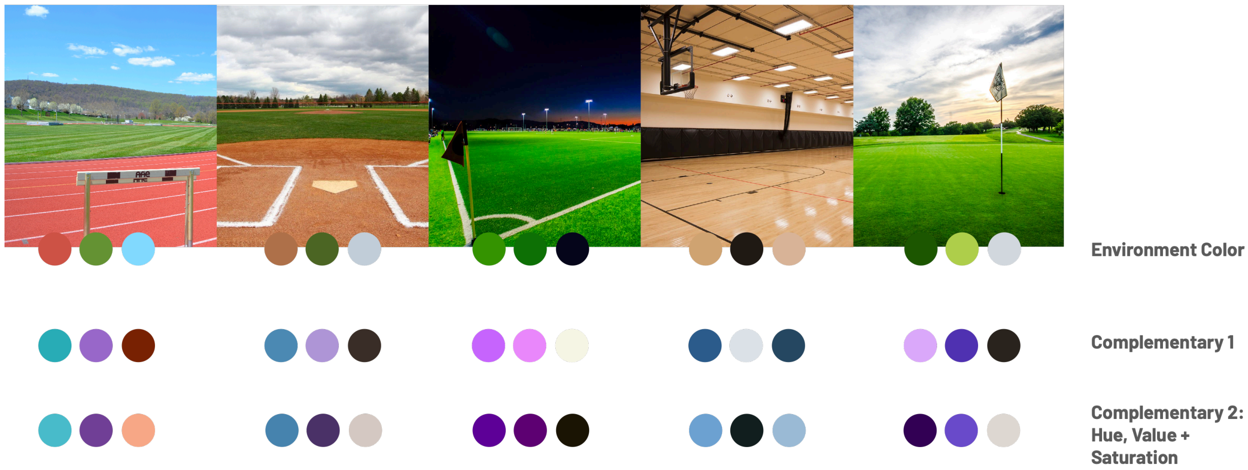


Figure 36 Color Exploration

Through several operations within the Adobe suit I took two approaches to finding the true complementary color. One involving hue and saturation as factors while the other did not. Both of these results fed into creating my final color palette for the men's and women's product. One consideration that needed to be taken into account when selecting the final colors for prototypes are what yarns there are available for me to use. The factory communicated a list of yarns they have on stock, as there will not be time to source a reasonable quantity of yarn and ship it to them within the time frame, I have for the thesis project.

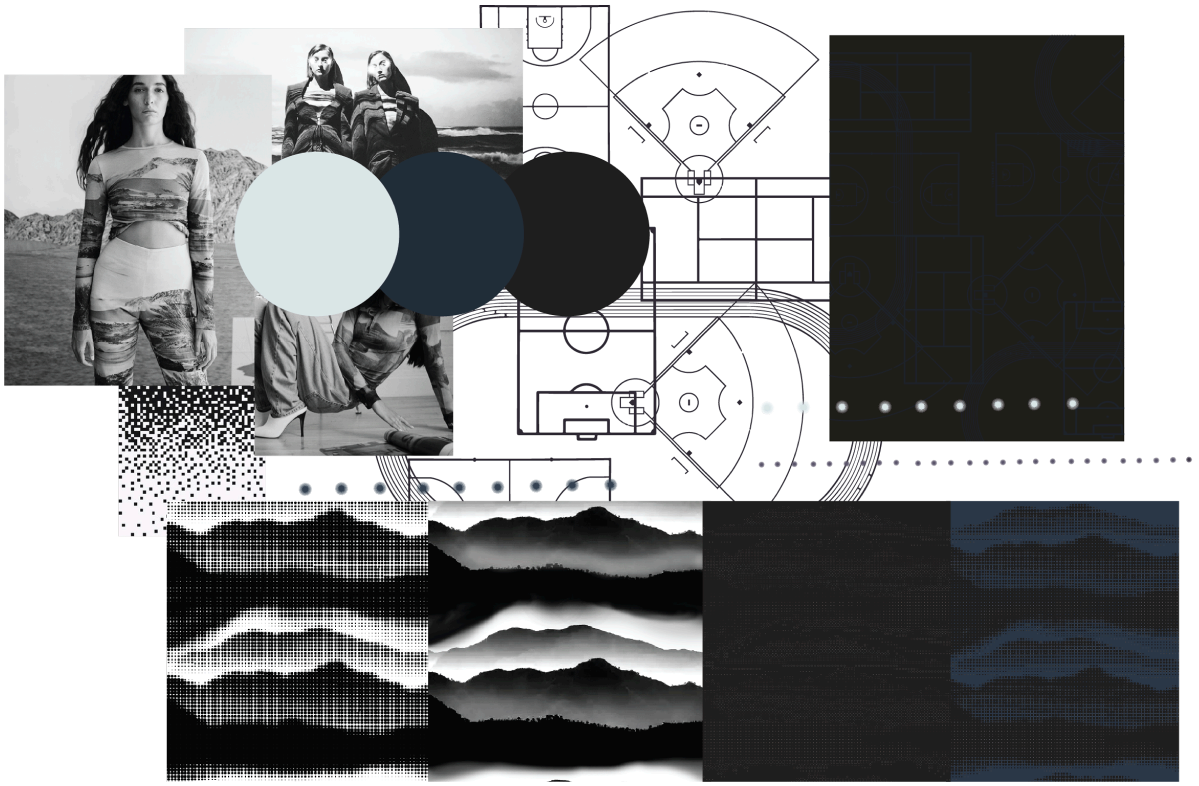


Figure 37 Graphic Exploration

Within *Figure 37* initial ideations for background colors create this contrast through dark tonal colors derived from the pallets in *Figure 36.* The concept was intended to provoke a sense of both digital and environmental inspiration. Taking images from natural environments, as well as sporting arenas and pixelating them in order to have a consistent product story.

In making final considerations for colors, a tonal pallet (shown in *Figure 37*) was decided upon due to a couple of reasons. First, contrasting orange/yellow graphics communicated a very high alert, crash dummy aesthetic. In hopes of the product being versatile and accepted moving away from this felt critical. I was able to have a conversation with Thomas Beibe, a senior software engineer at one of my baseline products companies, dartfish. He explained how the angle tracking element of the technology worked on a rudimentary level. Through this conversation I learned that simple technology, such as ones that could be integrated into an iPhone app actually process the videos in grey scale. This means that whatever color my products have need to have high levels of unsaturated contrast between the body and joint graphics. The tonal color pallet allowed the colors to still stand out in grey scale, yet not be so jarring to the naked eye.

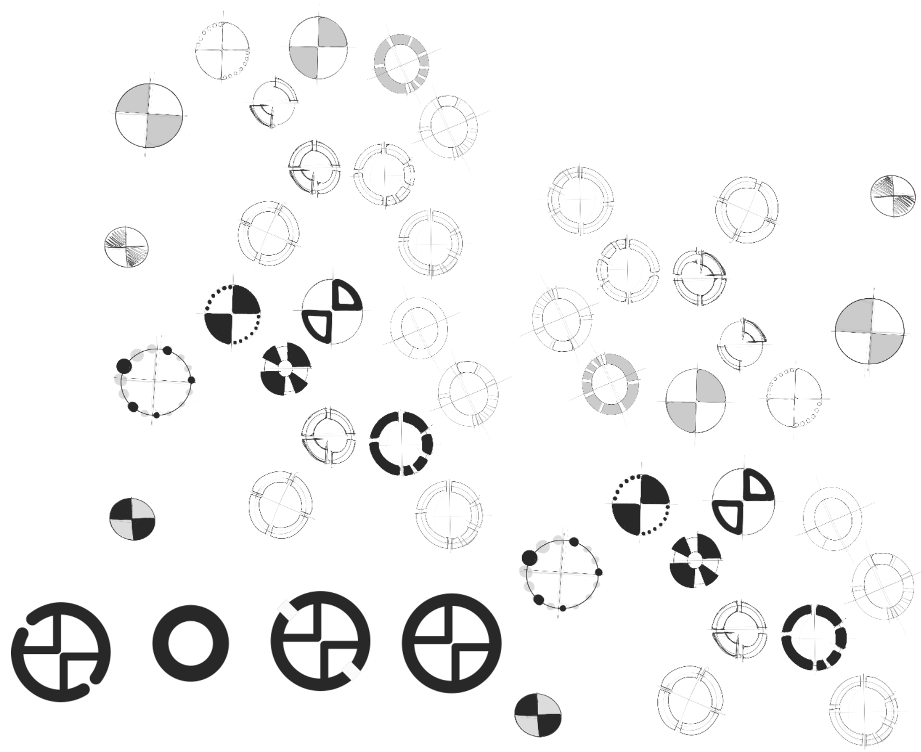


Figure 38 Joint Graphic Exploration

A second thing that was learned through the conversation with Thomas were specific shapes that computer programing is able to more accurately follow and track. A specific example is a traditional crash dummy marker, but other hard circle shapes were also effective. This lined up with my research exploration with dartfish tracking using leggings. The necessary piece was that there was contrast, and hard crisp lines. In ideating joint markers, I wanted to create something new, softer, with several variations. This exploration is shown in *Figure 38*. The shape that I decided to move forward with broke up the traditional 4 quadrants with open edges and rounded corners to soften the visuals without losing any effectiveness.

Final Garment System Creation

The following series of photos (*Figure 39-44*) display the technical package made to communicate the final design to the factory creating the textiles. Needed specifications of overall finished tube dimensions, zoning specifications and yarn colors were called out.

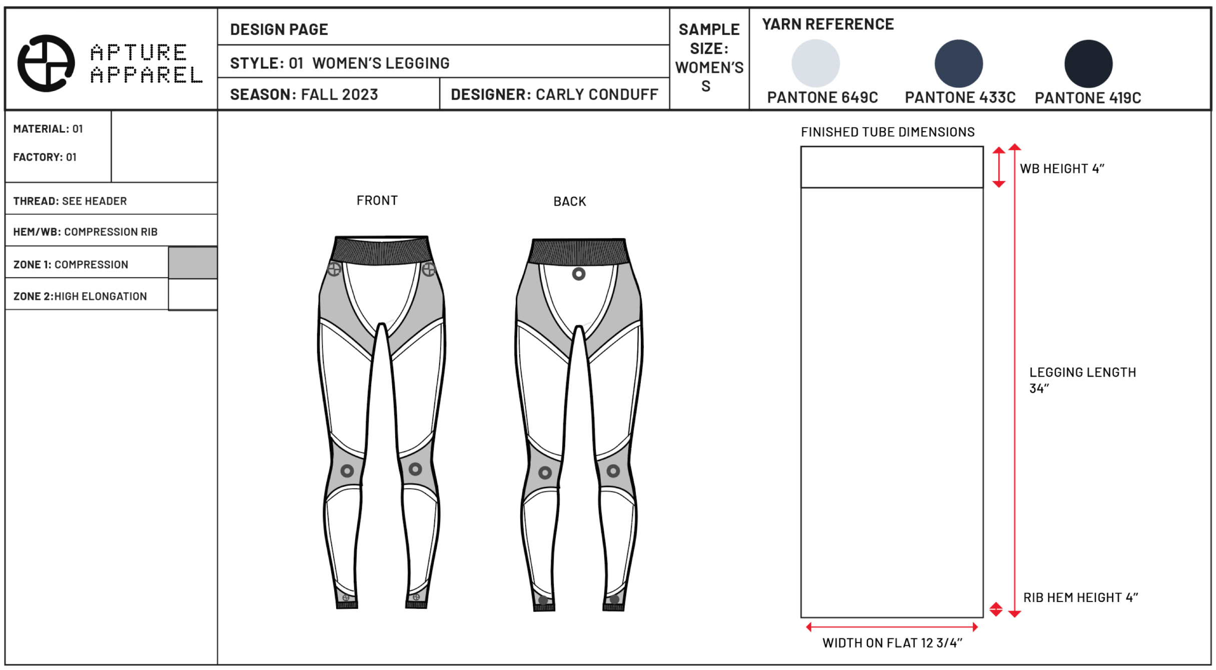


Figure 39 Legging Technical Drawing

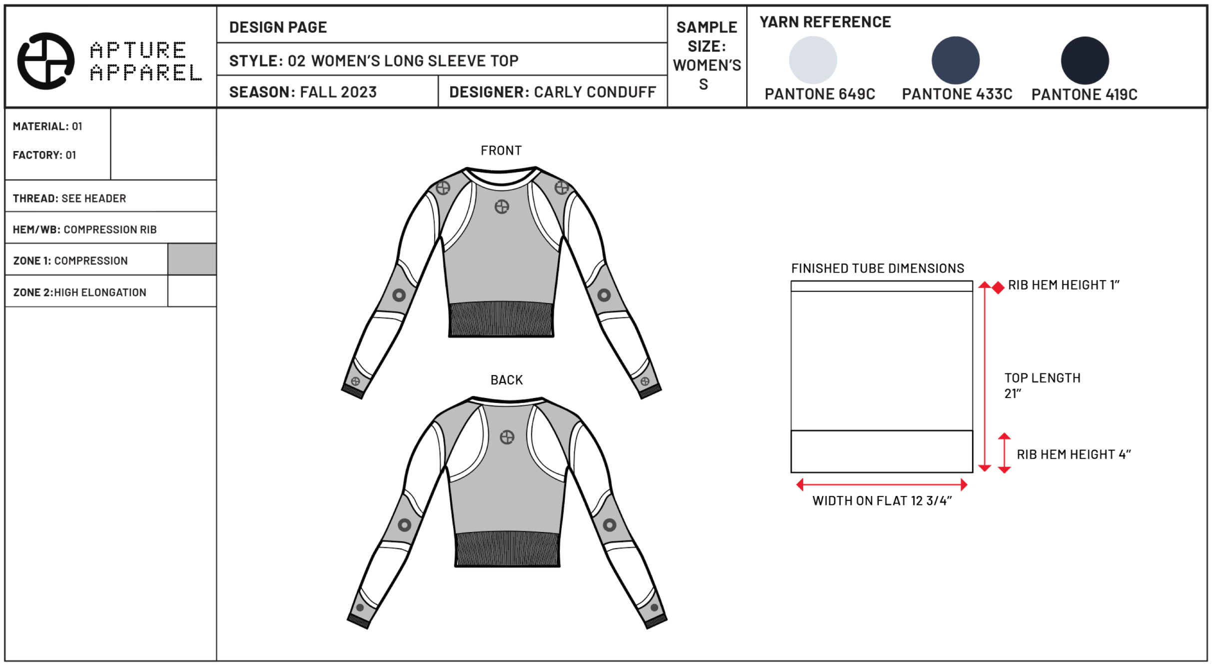


Figure 40 Top Technical Drawing

Figure 39 & 40

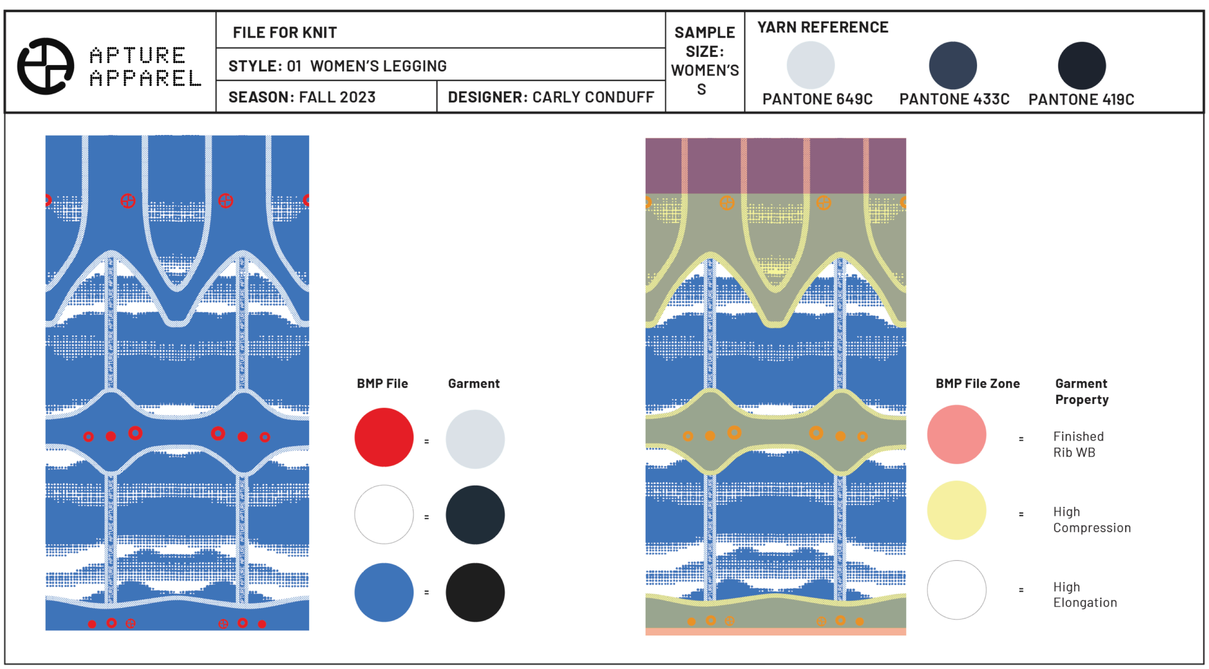


Figure 41 Legging BMP

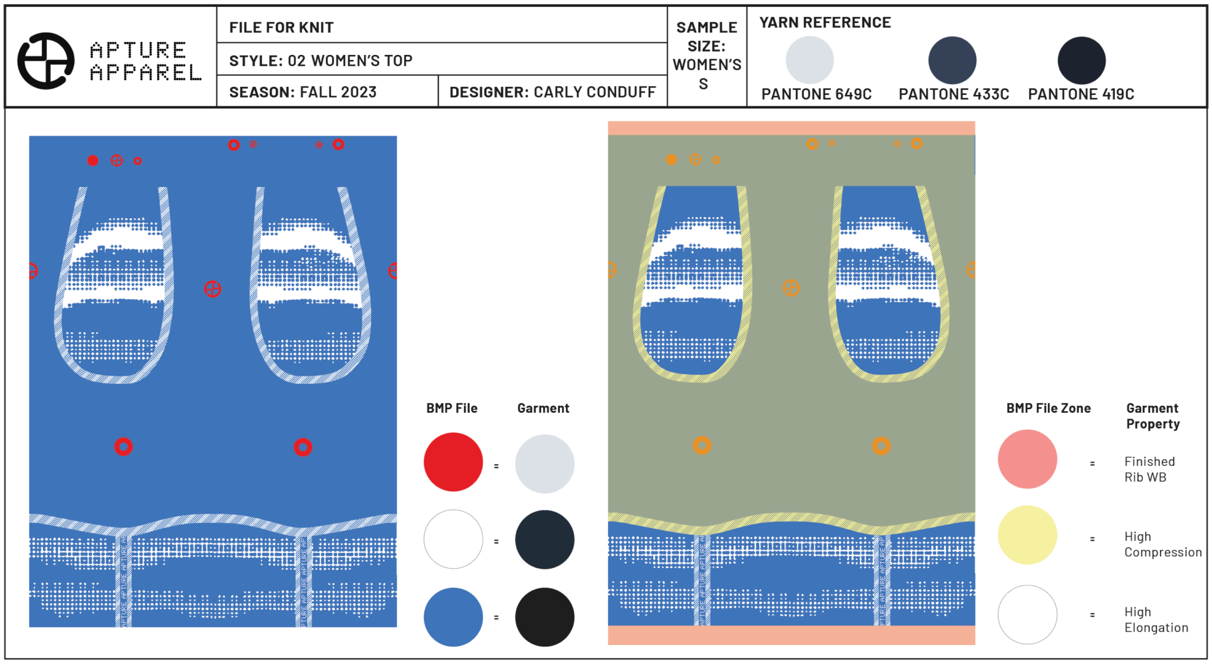


Figure 42 Top BMP

One of the most important pieces of getting these textiles completed was creating the BMPM file for the factory. While in many cases this work would not be done by the client, in order for it to truly be owned by me and give me an opportunity to learn the whole process, I created all of the files that got uploaded directly to the machines. The files were created with specific pixel ratios and then brought into photoshop to change the mode to selective local color before exporting the final BMP. I provided two files for each garment, one depicting the yarn color graphic details, the second having color coded functionality zones. These are shown in *Figure 41 and 42*.

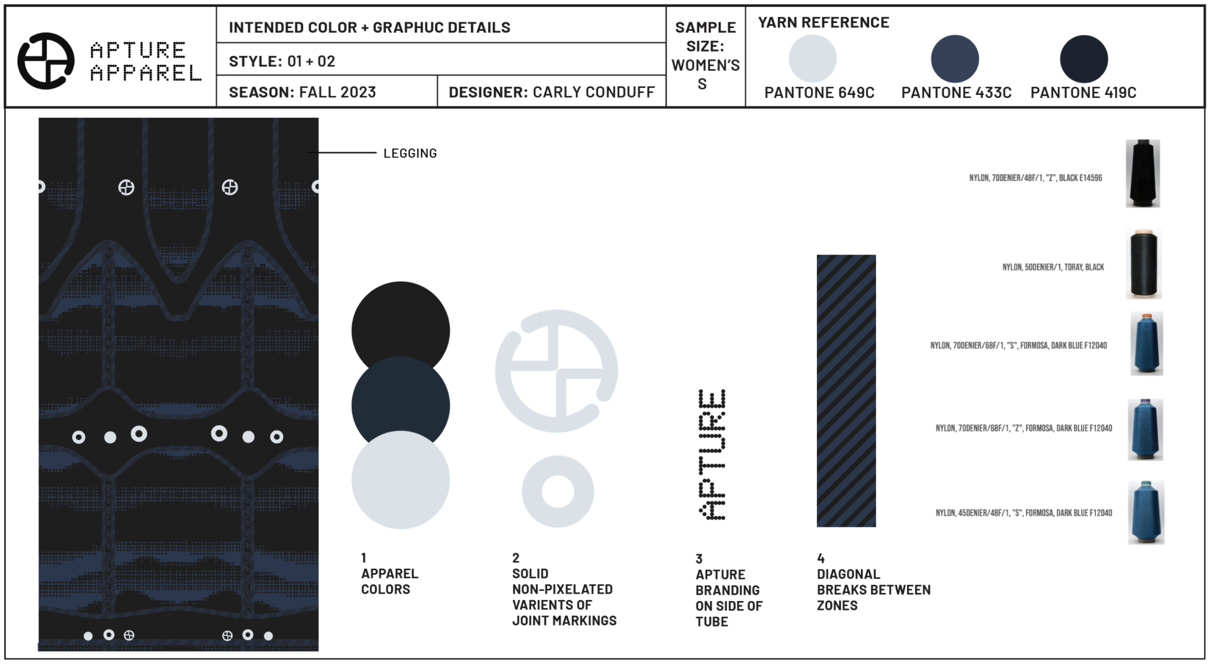


Figure 43 Graphics Callouts

Figure 44 Knit Development Revisions

There was a significant amount of trial and error in the first few days of developing these textiles. Between limited communication channels and the time difference it was a slow process to get questions clarified. Initial samples were made with only two yarn colors rather than 3 so I was not seeing the high contrast with subdued background that I was imagining. After moving to 3 yarn colors it took several trials to land the right accent color to achieve a knit combination I was happy with. An additional problem I was noticing on some samples is that the proportions were not turning out true to the file. For example, as depicted in some of the images in *Figure 44* the circular graphics were coming out oval just due to the shrinkage of the mechanical aspect of the knit. To resolve this we elongated the BMP files.

Figure 45 Final Garment Features and Benefits

The final garments were constructed from the tubes incorporating a gusset in the legging and raglan sleeves with a rib neckline for the top. The intended features and benefits are called out in *Figure 45*.

Figure 46 Final Garment Close Ups

The initial Apture product line garments followed through on the intended line plan and was executed with a male tight, sleeves and a female long sleeve and tight. While I was not able to secure different diameter knit tubes for the men's product. Due to the stretch of the material it was able to fit on a men’s size medium fit model. Both the leggings and top tubes were knitted with a 32G, 15’’ diameter machine.

Figure 47 Apture Packaging and Branding

Thinking about the project wholistically as a potential brand and how it would work in real life, it was critical to build out visuals for the user experience. Pulling from my graphics inspiration board I created hang tags, size labels, packing box and pamphlet that correlate with this visual theme of sports and technology. The UX flow is intended that the user opens their box with their Apture garments, scans the QR code on the card in the box and it prompts them to download the app and create a profle.

Figure 48 Apture App Home Page

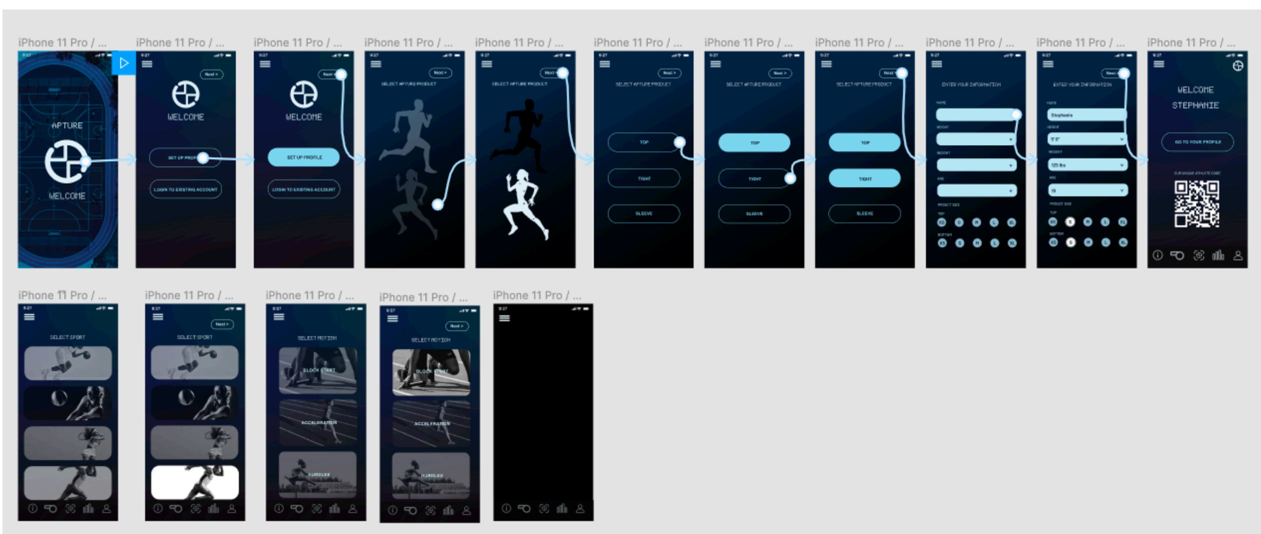


Figure 49 Apture App Wire Frames

The user would then create an account by selecting the product line they purchased from, the products they purchased and then physical stats about themselves. All of this process is shown in

Figure 49. The use of the garments they have and their stats will build out what sport movements they are able to capture form on, and what the proper form would be.

Figure 50 Apture App Correction Example.

For example, someone who just bought a basketball sleeve would be shown sport movements to capture only involving the angle of the elbow. The athlete shown in Figure 50 however, has the whole kit and can analyze more complex movements. For a block start, the app can recognize the hip, knee, ankle shoulder and wrist joints to tell several things. First, the angle of the power leg which should be around 90 degrees. Second, the hips should be well above the shoulders, with the shoulders rolling forward over the position of the hands (Harland MJ, Steele JR., 1997). Because the athlete entered their height, the app can calculate where these points should be for proper biomechanical form and compare them to where they are. From this the app can point out ankles/ locations that are too small/large and give a suggestion for correction as depicted in *Figure 50*.

In completion of this project, the ultimate goal is to provide athletes who otherwise would not have access or the knowledge to understand positional feedback, have access. By creating affordable, easy to digest technology that functions as regular sportswear it could be changing the game for both young athletes trying to get to the next level, but also coaches and trainers from all backgrounds to effectively teach and communicate proper form. Especially when understanding the urgency of young athletes practicing without physical peers, state of art facilities or coaches around, having a collaborative feature could reduce barrier of entry for sports for many athletes. Apture has a strong foundation to be able to mitigate these issues and a promising outlook on the future of training.

A

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