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BioHelm Smart Hockey Helmet: A Conceptual Wearable System for Protecting and Empowering Female Athletes

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BioHelm Smart Hockey Helmet: A Conceptual Wearable System for Protecting and Empowering Female Athletes

By

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Abstract

Women's ice hockey is one of the fastest growing sports in the world and needs the most articles of protective equipment. At the National Collegiate Athletic Association (NCAA) level, not only do these athletes need to adapt to team issued equipment that rarely fits comfortably or safely but must also consider the important facets that impact overall performance.

The main objective of this project is to promote inclusivity while protecting, empowering and educating athletes in an ethical, noninvasive manner to positively impact the culture of women's sports. Overexertion at the NCAA level increases exponentially due to the intense training and competition schedules and living the full-time "college lifestyle." This lifestyle can have negative anatomical, physiological, and psychological impacts on the athletes.

The year-long design project studied multiple perspectives, including players, coaches, trainers and doctors, using applied "design thinking" to create a holistic approach to solving sports equipment issues for women. This proposed system could improve the physical, physiological and emotional wellbeing of the athletes. The system combines physical biomarkers with player input in a multi-layered, systematic approach and to consider the potential of AI and "big data" gathered from the wearable technology athletic equipment to design the future for elite women's sports.

Keywords: **Women Athletes, Biomarkers, Sports, Health, Wearable Technology**

Introduction

Why do people participate in high impact sports if they are putting themselves at risk to get injured? Competition, identity, team camaraderie and culture are all common motivational themes that are infectious amongst collegiate athletes.

These seemingly positive aspects of athletics attempt to outweigh the underlying effects of competing in a high impact sport while also being a fulltime college student. According to the Center for Disease Control (CDC), out of approximately 500,000 student athletes there are on average 210,000 reported injuries every school year.[1] Good daily habits of adequate sleep, nutrition, and hydration can fail to persist when focusing all efforts on school and sports. Lifestyle choices can impact physical, physiological and emotional wellbeing on a day-to-day basis, let alone the long-term effects. These variables, working in together can eventually lead to mental and physical overexertion.

Societal problems include stigmas about understanding mental health, overexertion, nutrition and women's health, are all real-world issues that many people avoid discussing and learning about. Through this project's front-end research process, commonly discussed topics created insights which fueled the direction of this study.

The purpose of this research focuses on addressing the needs of female athletes in competitive environments where harm may result due to the lack of sports products designed specifically for women.

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[1] Dr. Zachary Y. Kerr PhD, et al. "College Sports Related Injuries." *Centers for Disease Control and Prevention (CDC)*. December 11, 2015.

Initial Research

Despite the overarching danger of potential injury, women's ice hockey has continued to rapidly expand due to the progress of hockey at the international and collegiate levels.[2] In the NCAA, women's ice hockey is in the top three most dangerous women's sports based on injury rate during competition and practice regardless of the amount of required protective equipment.[1] Men and women are also required to wear the same amount of protective equipment. At the NCAA level, "checking" or body-on-body contact is not allowed in NCAA women's sanctioned competition, while it is allowed in the men's divisions. A current professional women's hockey player explained, "people don't think we get hurt, they think there isn't any contact, people don't think women's hockey is dangerous."

According to a systematic review conducted by the Orthopaedic Journal of Sports Medicine, not only was the mechanism of injury the same (player contact), but "women in college suffered from higher rates of head and face injuries than men, and they also sustained high numbers of knee, thigh, and ankle injuries."[3]

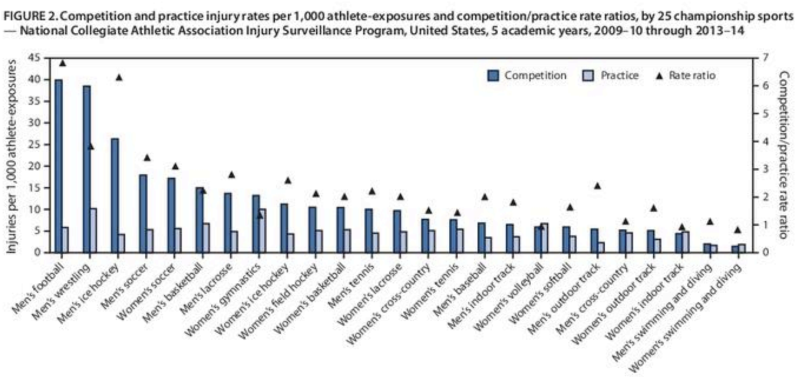

Figure 1 - NCAA Competition Injury rates per 1,000 athletes 2009-2014[1]

In competitive athletics, it is vital that all parties involved understand the importance of preparation, performance and recovery. Some common themes in expert interviews were training,

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[2] Sports & Development, Women's Hockey 2018. International Ice Hockey Federation (IIHF). Accessed February 14, 2022

[1] Dr. Zachary Y. Kerr PhD, et al. "College Sports Related Injuries." *Centers for Disease Control and Prevention (CDC)*. December 11, 2015.

[3] MacCormick, Lauren, Thomas M. Best, and David C. Flanigan. "Are There Differences in Ice Hockey Injuries Between Sexes?: A Systematic Review." *Orthopaedic Journal of Sports Medicine*, January 2014.

nutrition, hydration, overexertion and safety. These subjects lead to extensive research through the lens of trainers as well as a nutritionist and doctor. One strength and conditioning coach explained, “College is difficult, nutrition and recovery is so hard. Athletes and trainers need to be aware of what their bodies are telling them; reaching exhaustion is not the proper way of training, especially in season.” The strength coach clarified that continuous overexertion could increase injury risk for an athlete. The combination of negative training, recovery, and nutrition habits can have detrimental implications to an athlete’s physical, physiological and emotional states.

Women’s health has serious implications on their holistic wellbeing as well as success as an athlete. Consistent overexertion and fatigue can lead to hormonal imbalances that causes amenorrhea and negatively affects athletic performance but can also increase a woman’s risk of infertility, sexual dysfunction, adrenal malfunction, and osteoporosis later in life.[4] These detrimental health implications are not commonly spoken about and not well-known topics. In a personal interview with a nutritionist and women’s health advocate on October 12, 2021, she explained:

> “A lot of women aren’t aware of hormone disruptions caused by overexertion. Sometimes there is a huge advantage because our pain threshold is much higher, we can push ourselves and recover faster. This information is extremely valuable, there is a window where women are at a higher risk for injury.”

Focusing on the women’s health and athletic success, the Handbook of Sports Medicine and Science explains the three components “Female Athlete Triad,” energy availability, menstrual function and bone mineral density. The athlete’s current state migrates the chart in *figure 2* depending on her diet, exercise habits and energy availability affecting overall hormone fluctuation and holistic health.[5]

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[4] Dr. Emily Kiberd. “The Top 5 Risks of Overtraining for Females.” *Urban Wellness Clinic.*

[5] Mountjoy, Margo, ed. *Handbook of Sports Medicine and Science : The Female Athlete*. Somerset: John Wiley & Sons, Incorporated, 2014. Accessed February 26, 2022. ProQuest Ebook Central.

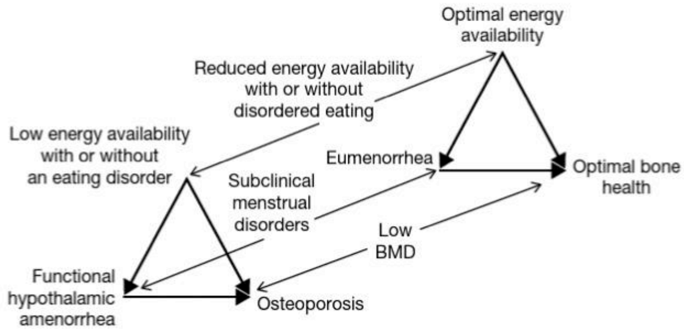

Figure 2 - Female Athlete Triad - The spectrums of energy availability, menstrual function and bone mineral density[5]

These aspects are essential to the holistic wellbeing of a female athlete however research previously discussed is important but not always the case. For example, women utilize different forms of contraceptives. Birth control impacts menstrual cycles and can completely disregard the connection with menstrual function mentioned above. This is an important reminder that all people are unique and have varying physiological needs.

[5] Mountjoy, Margo, ed. ***Handbook of Sports Medicine and Science : The Female Athlete***. Somerset: John Wiley & Sons, Incorporated, 2014. Accessed February 26, 2022. ProQuest Ebook Central.

Problem Statement

How can female athletes who compete in high impact sports gain a sense of protection, belonging and empowerment?

Design Goals

The design goals target user needs: to design a system that physically protects, while improving the athlete's physiology and emotional wellbeing. These aspects are intended to create awareness and educate athletes while also creating a sense of psychological empowerment through confidence in what an athlete wears and how they portray themselves.

Figure 4 – Design goals

Initial Ideation

Based on the initial research and findings, potential solutions were generated. These initial ideas were based on the following categories: safety, anatomy, physiology, and emotional wellbeing of the athletes.

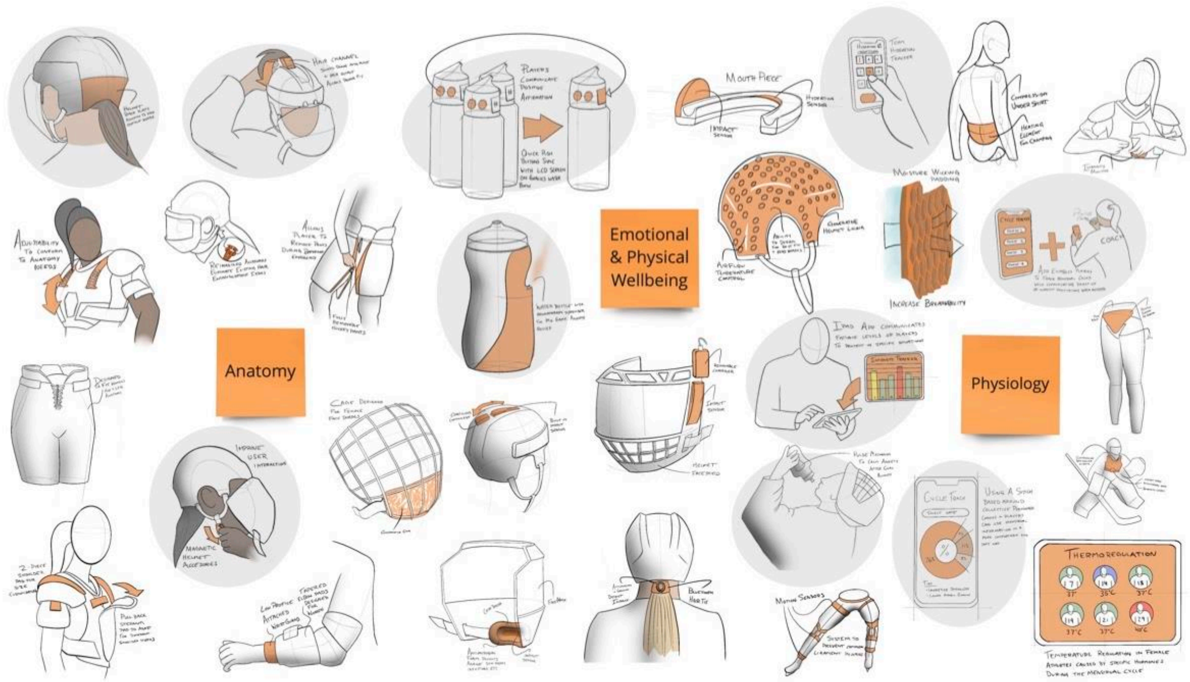

Figure 5 – Initial ideation sketches

Concept Refinement

The physical well-being concept focuses on the athlete’s physical safety, anatomical fit and overall user interaction. Existing helmets do not always fit properly due to different hair types. This helmet could give players a way to portray themselves through their equipment. Furthering this concept has the potential to explore integrated technology while using biomimicry and generative design.

Figure 6 – Physical wellbeing concept

The physiological well-being concept is focused on increasing the awareness of player fatigue and recovery. Using daily wellness surveys, fatigue, hydration, and hormone tracking to monitor overexertion to educate the athlete and prevent injury.

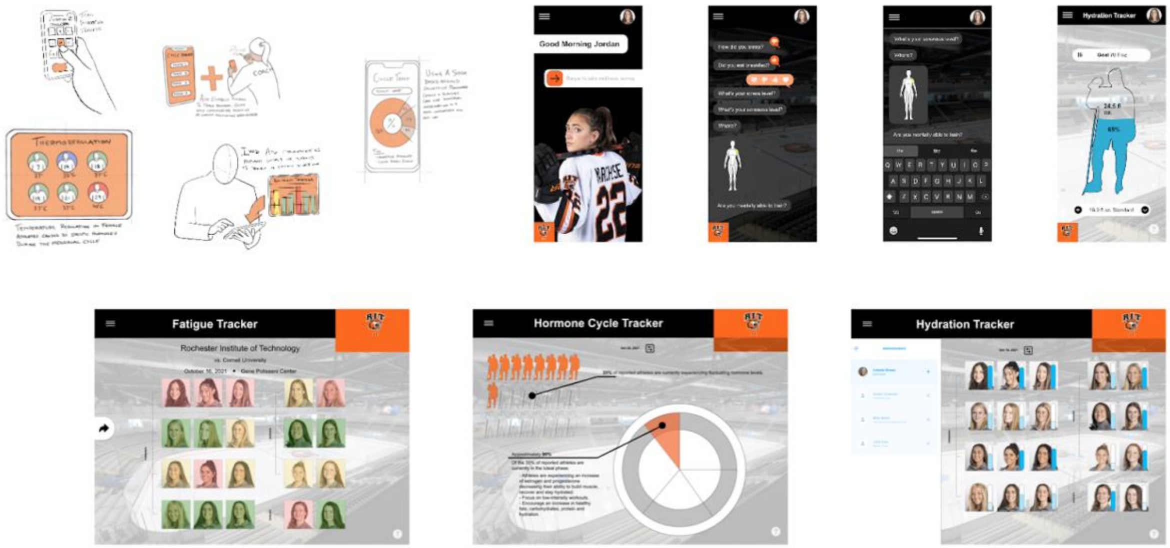

Figure 7 – Physiological wellbeing concept

3.3 Further Research

Athletic needs require a variety of attentiveness and common feedback supported by a product that quantifies well-being. When researching future trends in health & wellness, measuring biomarkers by decoding saliva and sweat was a topic that continued to resurface. The Gao Research Group at California Institute of Technology is on the forefront of bioelectronic eccrine sweat wearable sensors. Utilizing biomarkers in eccrine sweat such as sodium, chlorine, potassium, along with various neuropeptides can assist in decoding and quantifying exertion, fatigue, recovery, hydration, cognitive function and stress, noninvasively in real time.[6]

[6] Seshadri, D.R., Li, R.T., Voos, J.E. *et al.* Wearable sensors for monitoring the physiological and biochemical profile of the athlete. *npj Digit. Med.* 2, 72 (2019). https://doi.org/10.1038/s41746-019-0150-9

Biomarker	Justification to measure biomarker for the athlete	Concentration		Recognition element		Sensing modality	
		Saliva	Eccrine sweat	Saliva	Eccrine sweat	Saliva	Eccrine sweat
Alpha-amylase	Stress levels[140,141,142]	5–17 U/mL	–	α-Glucosidase, glucose oxidase, mutarotase	–	Biorecognition element	–
Glucose	Fatigue (e.g., hyperglycemia and hyperinsulinemia)[44,59,60,143,144,145]	1 µM	10–200 µM	Glucose oxidase	Glucose oxidase	Chronoamperometry	Chronoamperometry
Lactate	Workout intensity determined from measuring lactate inflection point[45,47,55,56]	5–50 µM	5–20 mM	Lactate oxidase	Lactate oxidase	Chronoamperometry	Chronoamperometry
Phosphate	Oral health,[146] uremia[146]	3.6–300 µM	–	Lactate oxidase and Prussian Blue or pyridine-oxazoline	–	Amperometry	–
Na^+	Hyponatremia[29,30,31,35,147]	–	10–100 mM	–	Na ionophore	–	Potentiometry
Cl^-	Fatigue[148]	–	10–100 mM	–	Ag/AgCl	–	Potentiometry
K^+	Hypo/hyperkalemia[44]		1–18.5 mM	–	K ionophore	–	Potentiometry
pH	Indicative of lactic acid build-up due to increase in $[H^+]$[55,149]	–	3–8	–	Polyaniline	–	Potentiometry
NH^{4+}	Fatigue; differentiate change from aerobic to anaerobic state[46]	–	0.1–1.1 mM	–	Ammonium ionophore	–	Potentiometry
Orexin A	Cognitive function and stress levels[113]	–	pg–nM	–	ZnO FET	–	Biorecognition element
Cortisol	Cognitive function and stress levels[111]	–	8–140 ng/L	–	ZnO, MoS_2	–	Electrochemical impedance spectroscopy

Figure 8 - Sampling of biomarkers which have been measured noninvasively from saliva and eccrine sweat sensors for monitoring human performance[6]

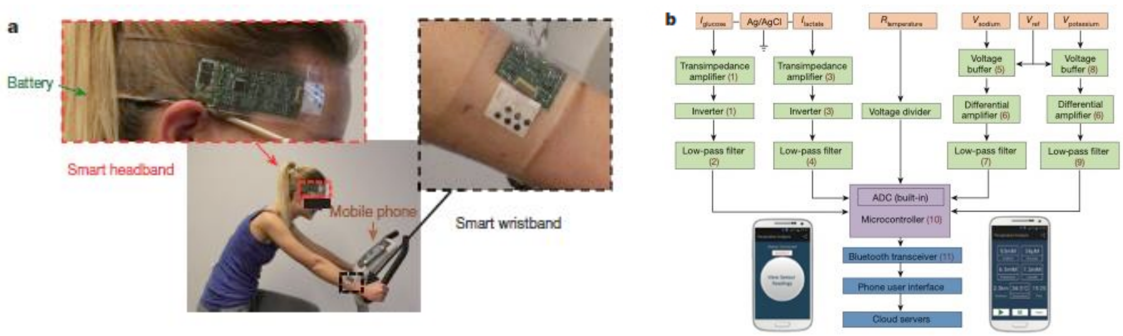

Figure 9 – Wearable perspiration sensor system overview [7]: A, smart headband. B, System overview.

[6] Seshadri, D.R., Li, R.T., Voos, J.E. *et al.* Wearable sensors for monitoring the physiological and biochemical profile of the athlete. *npj Digit. Med.* 2, 72 (2019).

[7] Gao, Wei, et al. "Fully Integrated Wearable Sensor Arrays for Multiplexed in Situ Perspiration Analysis." *Nature* 529.7587 (2016): 509-514L. *ProQuest*. Web. 6 Mar. 2022.

Concept Direction and System Architecture

The final concept merges three categories: safety, physiology and education. These themes create an overarching focal point of emotional well-being through protection and self-awareness. The components consist of a helmet integrated with an eccrine sweat sensor, a heart rate monitor and a smartphone application.

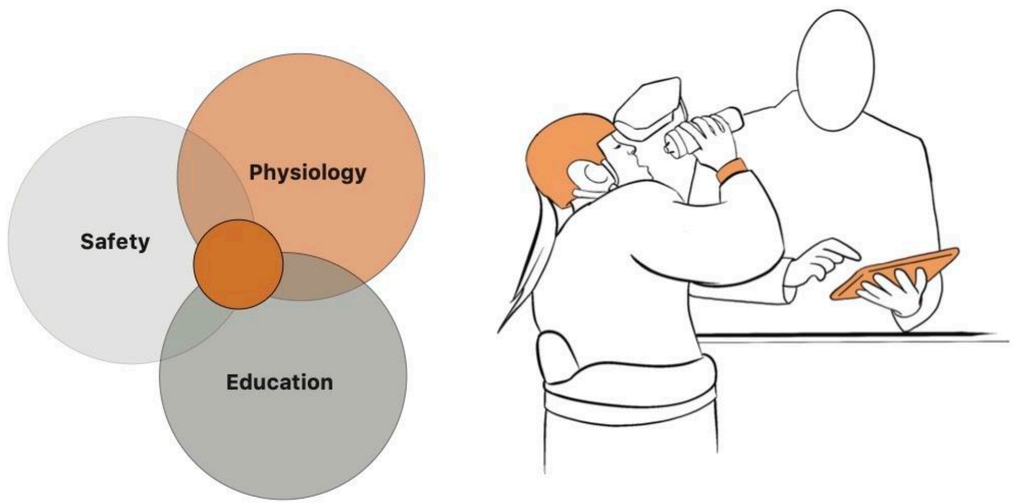

Figure 10 – Final concept direction

The system's architecture has three types of input that work as agents within the artificial intelligence software to utilize machine learning in an ethical manner to maximize performance, decrease injury potential and emotionally empower the athlete. The three types of input include biomarker data from the eccrine sweat sensor, heart rate information and manual user input.

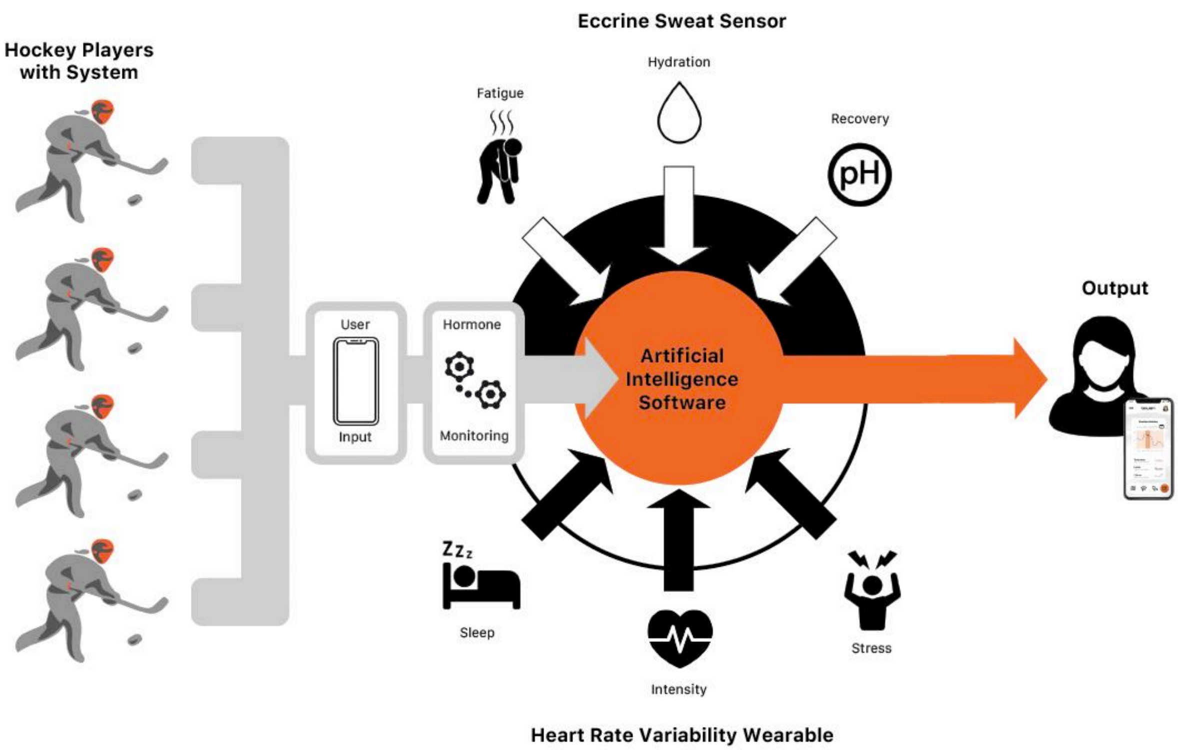

Figure 11 – BioHelm system overview

Prototypes, User Testing and Validation of Final Concept

The prototypes were tested by NCAA women's hockey players, a head hockey coach, a strength and conditioning coach as well as a nutritionist and women's health advocate. The users were asked to consider the overall impact of the system's features on women's hockey.

The heart rate monitor was 3D printed using a combination of flexible and rigid filaments. The users were given the heart rate monitor and asked their thoughts on location, user interaction, materials, comfortability and information communication.

Figure 12 – Heart rate monitor prototype and user testing

The helmet component was prototyped using an existing hockey helmet and modified using thermoplastic and a closed cell foam for internal padding. The prototype features three different outputs to adapt to the user's preferred hairstyle. The helmet was embedded with a microcontroller and galvanic sensor used to demonstrate how a helmet could begin to read information from eccrine sweat pores.

Figure 13 – Smart helmet prototype with embedded galvanic sensor

The users were asked to attempt to don the helmet using the hair outputs. It was necessary to understand if this interaction was intuitive. The users then tested the embedded sensor to understand the possibilities of wearable technology in athletic equipment.

The smart phone application prototype will be used to demonstrate how this information is collected and analyzed, as well as communicated output to the user. The main objective is to understand which folders of information are most important for the athlete to access and were asked to experience the interface.

Figure 14 – Users experiencing app feature and potential insights

While understanding the system architecture is essential, this process was most valuable to understand the comprehensiveness to the user. Lastly, this portion of testing focused on the ethical boundaries of sharing this information with artificial intelligence or medical professionals. Creating ethical boundaries to develop a system of products that does not make a user uncomfortable but empowers them.

4.0 Final Design

Figure 15 – Final design photoshoot

The final design consists of a three-component system utilizing a wearable heart rate monitor, a biomedical sweat sensing helmet and a smartphone application.

Figure 16 – BioHelm heart rate monitor

Figure 17 - Hydration color feedback through heart rate monitor and component view

This heart rate monitor is meant to be worn all day. The wearable's nucleus is a clear pod housing the electrical components and is wirelessly chargeable. This wearable also acts as a hydration communication device to the athlete during practice or competition. The athlete will double tap the wearable with their free hand to initiate an optical feedback loop using color. The internal nucleus can be removed from the external durable silicon housing to be placed in a chest strap. The clear silicon housing is just cloudy enough to still see the internal pod's colorful feedback. The strap is composed of elastic and a magnetic clasp that allows for adjustability.

Figure 18 – Helmet internal components

The helmet is made up of an external adjustable shell, internal generative padding structure and electrical components that include an eccrine sweat sensor. The external shell features a futuristic aesthetic that offers adjustability in a way that has not been done in a hockey helmet before. This feature is also accompanied by strategically placed hair outputs for the player, allowing an intuitive fit and opportunity for self-portrayal. The biomedical components include a replaceable potentiometric sweat sensor, flexible printed circuit board design with integrated Bluetooth technology and a wireless rechargeable battery. The components are carefully housed in a compartment designed to fit non-invasively in the crown of the helmet. It will allow for the helmet to noninvasively communicate sweat data in real time to the user's phone.

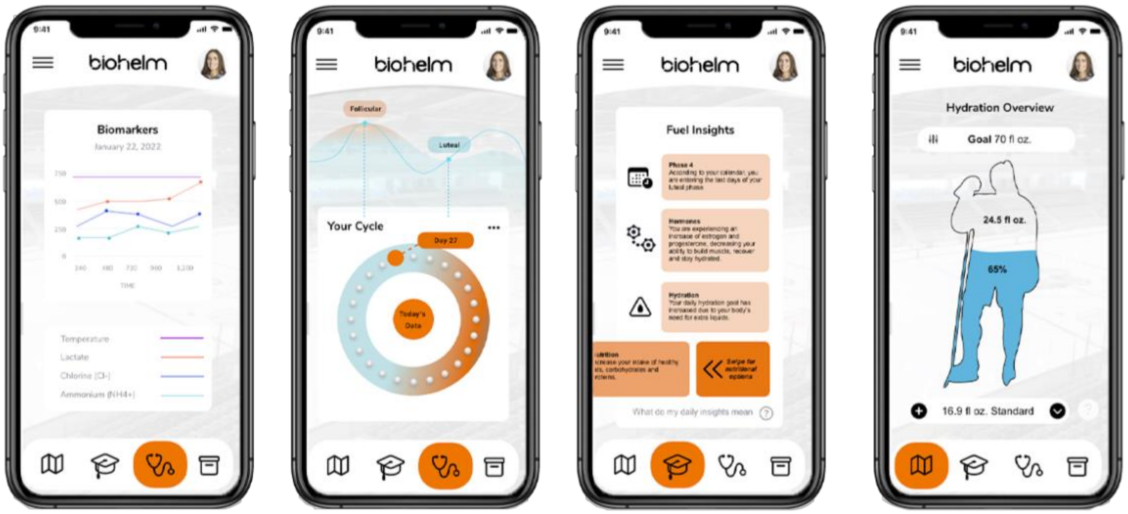

Figure 19 – Smartphone interface

The phone application utilizes four main folders: exertion, health, hydration and recovery. These different folders collect information from manual user input, heart rate variability and biomarker data from the sweat sensor. Each feature includes a section overview, biomarker information, historical archives and the insights. The insights section is essential for the software to decode the information that is collected to provide comprehensive output for the user to make impactful decisions. Another important feature is the software collaboration adjustment between folders. For example, if your exertion level is high and the athlete is in a specific phase in her cycle, the app will increase hydration goals and give insights on how to improve nutrition based on the user's current physiological state. Overall, this application is designed to help make educated decisions when preparing for and recovering from competition.

5.0 Conclusion

Overall, major insights were gathered during testing and the system was considered to be useful. The user's excitement truly showed during testing when talking about their experiences and how a noninvasive biomarker system embedded in equipment could have such a positive impact through education and awareness.

The final design targeted three main user needs: physical, physiological and emotional well-being. This proposed product solution meets user needs through tangible and intangible feelings of safety, empowerment and belonging. Understanding empowerment and women's health is essential in unlocking the full potential of the athlete while not only protecting their wellbeing during competition but later in life.

A substantial portion of this project consisted of ethical research in relation to the levels of artificial intelligence and machine learning in collaboration with intimate data collection and analysis. The system's architecture lives within boundaries, collecting and interpreting data that is communicated to the athlete, for the athlete. As culture progresses, the potential of these systems should be reevaluated and altered based on needs and cultural acceptance.

While this design has a niche target market, this system can be adapted by any sport and gender to make a positive impact with an inclusive approach. Prioritizing enablement and self-awareness to an athlete are ways to improve athlete culture while impacting the industry in a positive way.

Next steps in this project would be further exploration in engineering, manufacturing and software development. Developing this case study further would allow this system to redefine protective equipment across all high impact sports.

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(1) Dr. Zachary Y. Kerr PhD, et al. “College Sports Related Injuries.” *Centers for Disease Control and Prevention (CDC)*. December 11, 2015.

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(3) MacCormick, Lauren, Thomas M. Best, and David C. Flanigan. “Are There Differences in Ice Hockey Injuries Between Sexes?: A Systematic Review.” *Orthopaedic Journal of Sports Medicine*, January 2014. https://doi.org/10.1177/2325967113518181.

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