Jack Marcisz - 2020

Pacer: The Power of Mobility

by

Jacek Marcisz

Supervised by

Dennis Kappen

Catherine Chong

&

Sandro Zaccolo

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Student Name: Jacek Marcisz

Abstract

Amputation is the surgical removal of all of or part of a limb or extremity such as an arm, leg, hand, toe, or finger. The most common type of amputation is a complete or partial lower limb amputation due to vascular diseases such as diabetes and peripheral artery disease. The removal of a limb is traumatic and life changing event, which forces the people involved to make drastic changes in their lives in order to cope with the disability. After a major amputation, the main goal of rehabilitation is to return to as normal a life as possible. A major factor playing against those who have had a lower-limb amputation is their mobility. Partial or total removal of a major supporting limb not only causes disfunction of mobility, but also many physical ailments or relating connective tissue and human ergonomic factors such as: hip displacement, spinal torsion, balance, reduced mobility, pain, and posture. This change causes those with the new disability to adopt new methods of transportation in order to regain mobility without relying on others aiding them. The aim of this project is to develop a product that will improve the mobility of those who have suffered a lower-limb amputation, improving their quality of life and reducing the ailments that come with it. Research was conducted to gain insight on common issues afflicting amputees. The proposed product will take into consideration the current methods and factors involved in the mobility of amputees, and suggest a useful and feasible solution. Those affected by reduced mobility due to lower-limb amputation will be able to efficiently and comfortably enhance their mobility while reducing strain, returning them to optimal mobility performance.

Acknowledgments

This project is the culmination of four years of study at Humber College, in the bachelors of industrial design program. First off, I would like to thank my parents Lucyna and Peter. Without them and their support I wouldn’t have been able to make this possible. I would like to thank my sister Dominika, who is a constant inspiration and reminder to work hard. Thank you, Jenna Speir, for being by my side on this journey, staying so positive, and allowing me to grow. Thank you to my advisor Dr. Tyler Weaver, without your expert advice and direction this project wouldn’t have gained the traction and direction it needed in order to be completed. Without the expert advice and direction from the multiple advisors at Humber College, this project wouldn’t be possible. Thank you, Dennis Kappen, Catherine Chong and Sandro Zaccolo, for all of the advice, guidance, suggestion, class time, and mostly for putting up with all of us students. I would also like to thank all of the faculty in the Industrial design department, the knowledge and skill you have passed onto me will be valued and used to my full potential. Lastly, I would like to extend a big thank you to the entire class of 2020, these last 4 years have been stressful at best and mean at worst; the friendships will be cherished.

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CHAPTER 1: Problem Definition

1. Problem Definition

1.1 Problem Definition

Movement through an environment for most people is done with minimal effort, planning, or even thought. Living with an amputation, specifically a lower-limb amputation, changes the dynamic of movement and mobility through environments dramatically. While amputation may be a lifesaving procedure, the resulting impact of amputation can be lifechanging, presenting the individual with adjustments in almost all aspects of daily living and functioning. The dramatic change of having amputation of a major limb changes how the human body performs tasks and adapts to them, causing irregular strain to the body (Cristian, 2006).

These adaptations amputees develop for themselves are of significant importance and require attention due to the eventual outcome being associated health risks including musculoskeletal disease, gait abnormalities, hip displacement, residual limb pain, and spinal deformity (LaRaia, 2010). Amputation rates have not decreased over the last decade, in fact the incidents of lower-limb amputation are projected to double by 2050 (Imam, 2017). These factors have important implications for the future of personal, social, health care concerns regarding amputees and their rehabilitation.

This problem encompasses the full body interaction and ergonomics to help amputees. Improving their safety, comfort, control, and more so their ability to move through environments with less effort exerted. The resulting proposed product would be lightweight, modular, and accommodating to the fit of a wide range of body types.

1.2 Investigative Approach Taken

The cornerstone of any good design solution is the understanding of its users, in this case lower-limb amputees. In order to understand the user, various methods of design research were conducted. These methods not only helped understand the user, but also heled to enhance the final proposed design solution. The methods are as follows:

- Literature Reviews
- Statistical Reviews
- Existing Product Benchmarking
- One-on-One Expert Interviews with Users and Health Care Professionals
- User Observations
- Ergonomic Studies
- Sustainability Studies
- User Activity Mapping

In order to develop a deeper understanding of the problem and the users that are directly affected by it, informal interviews were conducted with the aid of pre-thought out questions that were considered relevant or helpful in retrieving pertinent information. In using prepared questions, the flow of the interview was unimpeded allowing for further question development. Some of these questions concerned ergonomics, donning and doffing, use, balance, mobility, etc. all of these questions were used to answer some unknowns that would be considered “bigger picture” questions. These unknowns are as follow:

- Demographics of amputees
- Products currently being used
- Amount of time devices are used
- Have these users faced issues they consider problematic?
- Current Donning & Doffing Practices

- Thoughts about current products
- How do users deal with balance?
- How their bodies are reacting to the change (mentally/Physically)

1.3 Background, History, and Social Context

The amputation of limbs has been a part of human history for as long as human history has existed. The context is vast from war, to a form of punishment, and even as a form of medical healthcare. The removal of a limb is on of the most invasive surgical operations known, and up until recent human history, it was an operation that could save the life of a patient but was more likely to result in death. With the advent of superior medical technology, methods, and practices; the survival of amputees has increased dramatically. Furthermore, as the diets of society of shifted to more processed, sugary items; the rise of medical conditions such as diabetes, which directly increase the chance for and cases of cardiovascular related amputations, is at an all time high.

Amputation has been known to lead to financial strain, isolation and loss of self-esteem. An individual must adjust to changed appearance, becoming used to a body both with and without a prosthesis. Intimate relationships may be threatened following amputation (Atherton, 2006).

Prosthetics have their origin as wooden peg legs and have developed into hyper intelligent attachments that can measure, compute, and understand the gait of its user allowing for a more fluid motion, however some developing countries still employ archaic methods that utilize bike seat posts as prosthetics. Though these advancements exist, the market has not seen m design solutions that while improving mobility also improve the safety of the user and reduce or eliminate some potential health risks associated with long term repetitive use of prosthetics.

This is an issue that needs to be met due to the increase in incidents of amputations not only from health complications, but also from trauma. Developing a product that focuses on the human centred design of amputees will improve their over all quality of life.

CHAPTER 2: Research

2.1 User Research

Introduction

The foundation and starting point to any good design solution is the research of intended user demographics. Having an understanding of the user, their needs, wants, and current/future behavioural practices is crucial in problem solving that leads to a final design solution. This section of the report will identify who is being researched and their behaviours that they routinely exhibit. This is important for product development due to the nature of the final proposed design solution being able to improve the mobility and quality of life of the end user.

Objectives

1. To determine the demographics of the end user
2. To determine user behaviour related to this product
3. To generate a user profile
4. To identify the user of this product (primary, secondary, tertiary)
5. To create a persona that represents the “typical” user

Methods

Various research methods were used in order to collect data on demographics. User observations and user interviews were also used to collect data directly from current users. The findings were placed in the following results.

- User Profile/Persona
- Current user Practice

- Activity Mapping
- Ergonomic Study
- Safety & Health Review

2.1.1 User Profile

Introduction

Generation a fictional persona to design for is a useful tool used in problem solving because it helps understand the perspective of the user, it helps create empathy for the user, and it creates a ‘big picture’ of who the average user is and what their needs are. The fictional character profile in this section will be based on the average user demographic and will describe the user’s behavior, their needs, and their mobility practices relating to living as an amputee.

Objectives

- To determine the users (Primary, Secondary, Tertiary)
- To determine the demographics of the users
- To create a fictional user persona that represents the typical user

Method

Using research and data collection information was gathered about current users of related products. This information was then used to build a user persona based on the average demographics and users of similar products.

Results

Primary User – Amputee

The primary user is the amputee, those who have suffered a lower-limb amputation. These are the individuals who will be directly interacting with the mobility device and using it regularly.

Secondary User – Healthcare Provider

Healthcare providers are the secondary users, these individuals have personal relationships with the amputees and would have met them from the beginning of loss of limb, continuing till well after rehabilitation to end of life. These are the people who help them recover, keep them healthy, rehabilitate, and inform them on devices/device use.

Tertiary User – Family/Friends

Tertiary users are family, friends, and people who interact with amputees in public environments. They are the individuals who help care for the amputee after limb loss, potentially taking part in the healthcare aspect of post amputation. These can also be individuals who are interacting with amputees in public forums, such as holding doors open or aiding a fallen amputee.

Demographics

Age

The largest population of amputees (28.0%) is from 51 years of age to 60 years of age. 81% percent of amputees are over the age of 40 (O&P EDGE patient survey, 2011). Nearly 93% of amputees have been living with limb loss for more than 2 years (O&P EDGE patient survey, 2011). This indicates that even though that the median age of amputees is above the age of 40, those affected by limb-loss experienced the event much earlier. Over two thirds of amputations due to trauma occur among adolescents and adults below the age of 45 years (Ziegler-Graham, 2008).

Table 2.1.1.1:

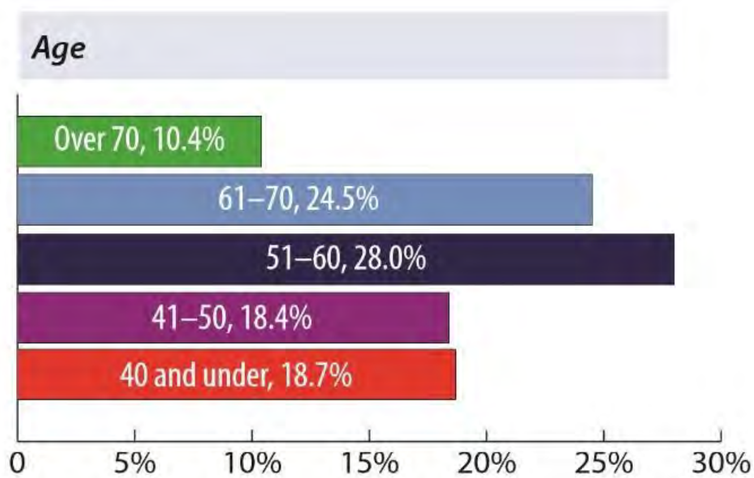
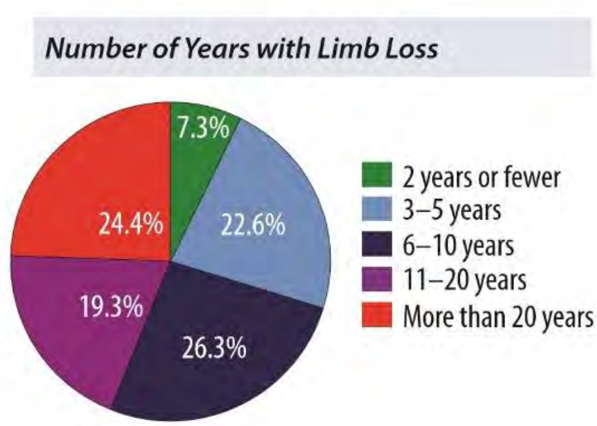


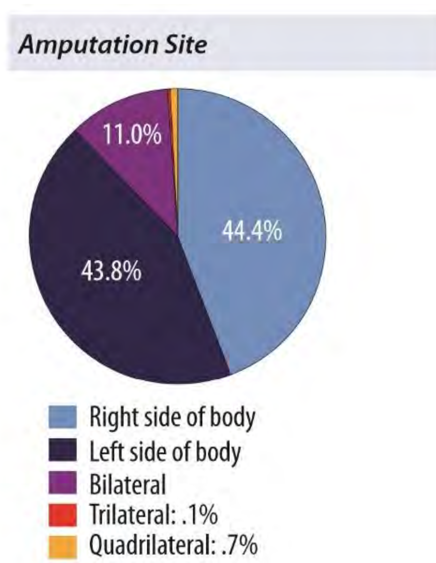
Table 2.1.1.2:



Cause/Type

Amputation is one of the oldest surgical procedures that are caused by many factors. Due to the variety of causes, a wide range of people are affected. 45% of amputations are caused by Traumatic incidents, this stat directly skews the demographics due to the unpredictable nature of some traumatic events. However, 54% of lower limb amputations are caused by health complications such as vascular disease, and 1% from cancer (Rajak, 2015). Lower-limb amputation is the most prevalent type of amputation, this includes symes, below knee, above knee, and hip disarticulation, which accounts for 90.3% of all amputations. There is not a prevalent skew between left (43.8%) or right (44.4%) of the body, however, 11.0% of people suffer from bilateral amputation (O&P EDGE patient survey, 2011).

Table 2.1.1.3:



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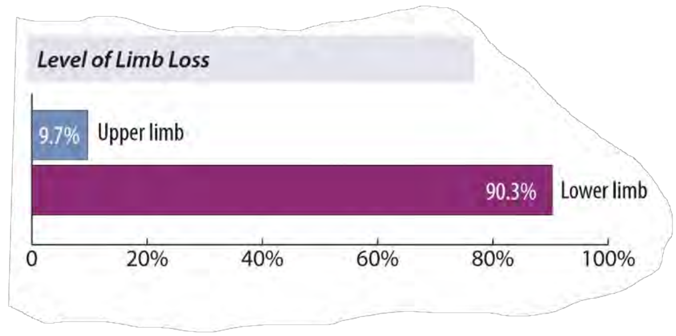


Ethnicity/Gender

The majority of amputations are Male (62.3%) to Female (37.7%). Ethnicity does not play a major dictating factor in amputation statistics (O&P EDGE patient survey, 2011).

Fictional Persona

Persona

Name:	Sebastian Boularice
Age:	36
Job:	Pipe Fitter
Income:	$85,000/year
Education:	Highscool Diploma
Relationships:	Married, First Child
Location:	Waterloo, ON
Type of Amputation:	Above Knee, Left side
Hours of Prosthetic Use:	14+
Cause of Amputation:	Trauma
Number of Years With Limb Loss:	5 years

Retrieved from: https://www.wbur.org/common-health/2018/04/13/step-ping-strong-brighamamputation.

User Behavior

Sebastian’s mobility relies solely on his prosthesis. When he wakes up in the morning it is part of his morning routine. He uses it when he drives to work, while he works, and during any other post work activities. He spends roughly 13 hours a day on his prosthetic, he feels very comfortable on it, even though he sometimes feels discomfort or soreness or the amputation site.

Sebastian’s Relationship with his prosthesis

Sebastian’s mobility would be severely limited without his prosthesis, he uses it for work, walking, and even driving. Without his prosthesis he would not be able to provide for his family. He uses it 7 days a week, he takes care of it with regular maintenance. Sebastian says that even though it is not his real leg, he doesn’t even have to think about how or where he walks anymore because of the amount of use he gets out of it. Some of his steps require more energy like going uphill, and he knows that it can become a safety hazard during the cold months. Sebastian relies on his prosthesis, and loves that he has been returned to mobility since his accident.

2.1.2 Current User Practices

Introduction

The purpose of finding this data is to understand what the user uses the product for, how they use it, how long they use it, and why they use it. This information will help inform the final design direction.

Objectives

- To determine the frequency and duration of use of existing products
- To determine the reason behind buying and using the existing products
- Find out where existing products are being used
- To find out regular tasks, procedures, attitudes

Methods

Prosthetic Habits

A majority of 95% of all amputees wear some form of prosthetic, and 81% were either satisfied or very satisfied with their device. Of the relatively small percentage of user who do not have a prosthesis, the primary reasons reported were that they didn't want one or were satisfied with other assistive devices. Other devices include; manual wheelchair, crutches, and electric wheelchair or scooter. Prosthesis users tend to wear it regularly, only 10.8% of users reported that they don't use it regularly (O&P EDGE patient survey, 2011). 82.7% of prostheses users wear their device daily, and more than half of those wear the device for 13 hours per day.

Table 2.1.2.1:

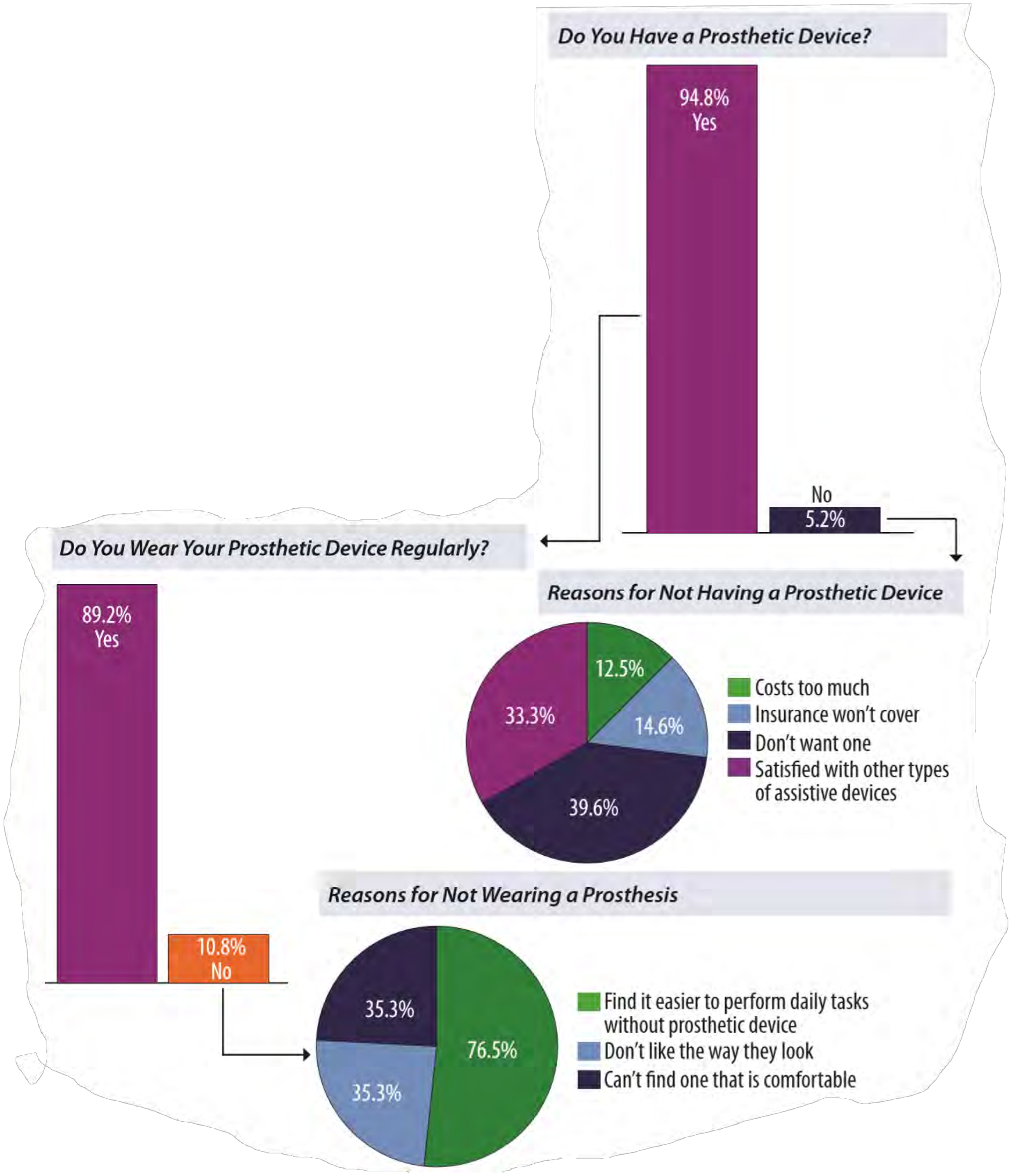
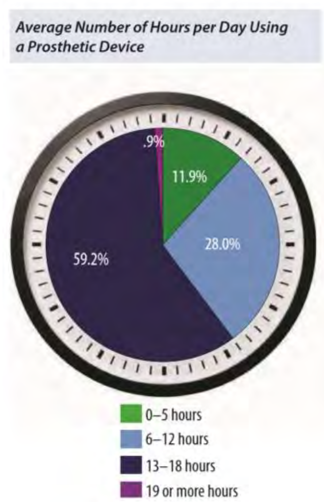
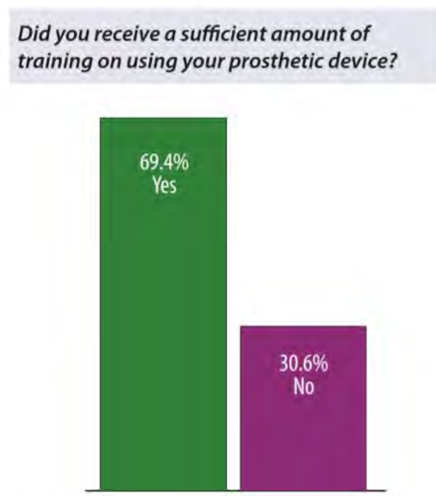

Do You Have a Prosthetic Device?
94.8% Yes
No 5.2%
Do You Wear Your Prosthetic Device Regularly?
89.2% Yes
10.8% No
Reasons for Not Having a Prosthetic Device
12.5%
14.6%
39.6%
33.3%
Costs too much
Insurance won't cover
Don't want one
Satisfied with other types of assistive devices
Reasons for Not Wearing a Prosthesis
35.3%
35.3%
76.5%
Find it easier to perform daily tasks without prosthetic device
Don't like the way they look
Can't find one that is comfortable

Table 2.1.2.2:





Buying Decision

Apart from amputation due to health risks, causation of amputation is largely unpredictable leaving the buying power of amputees very undetermined. In Canada Prosthetics are not covered under its universal healthcare, though the assistive devices program offered by the ministry of health and long-term care does provide partial coverage for prosthetics and orthotics.

Location

Amputees can be found anywhere, however, this largely depends on their personal health and weather or not they have access to mobility aids. In Canada, nearly 2 million people are living with limb loss, out of which 54% are due to vascular diseases including diabetes (Rajak, 2015). Diabetes is linked to obesity, which in itself is a major factor in a person’s ability to be mobile.

2.1.3 Activity Mapping

Introduction

Mobility concerning amputees is generally seen as an activity that can be hazardous and very strenuous. This means that moving through space without the support of a major limb isn't an activity most individuals experience or rather are forced to experience. For the purpose of this thesis project and being able to understand more how amputees and users of a prosthesis move, research was conducted to generate an activity log in regards to complex, strenuous, and potentially hazardous activities during movement for amputees. These activities include recovering from a fall and moving up and down steep inclines. Understanding these motions will help develop a design solution that addresses complex movement, balance, and safety.

Objectives

- To identify problem areas/risks during mobility for amputees
- Highlight key actions
- To identify complex gait/motor patterns
- To observe donning and doffing of prostheses'

Method

Observational research was conducted pertaining to the mobility of amputees and the use of prostheses.

Results

A regular day for an amputee is no different from anyone else's, except that they lack the support and use of a major limb. This thesis will focus on lower-limb amputees, those who have reduced or complicated mobility due to limb loss.

Living with amputation is not only difficult physically, but also mentally. It is something that amputees have to be concerned with for the rest of their lives; whether this means major tasks like how they will provide for themselves, to more simple tasks like how they will walk to the store, up a hill, to their bedroom.

Contemporary technology, materials, and manufacturing has brought about a change in how a prosthesis looks and works. Despite the advances made in current mobility devices., amputees are still recorded to spend upwards of 13 hours on their prosthetics (O&P EDGE patient survey, 2011). This suggests that future mobility aids need to support the lifestyle of a growing amputee population.

Observation

For this user observation, the user was recorded moving up and down hills, and recovering from a fall. Then later interviewer and user sat down and discussed details over the video. (transcript located in appendices)

Observing the user moving over steep incline up and down with a stop and turn.

ABOUT THE USER

Nam: Hayden Bailey
Age: 32
Sex: Male
Height: 6'
Date of Observation: 26/10/2019
Experience Level: Proficient, high level of skill.
Prosthetic Used: Genium by Ottobock knee with X3 protective cover, Triton low profile foot with slip toe.

STEP1: Assessment

- Approaching the incline the user slows his pace.

- Eyes up, he observes the path down making note of any difficult terrain.

- Planning route according to terrain.

Points of interest.

- Approaching Curb he leans forward pushing off with rear leg.

- Arms dont swing but rather raise forward. (note shoulder hunch)

- Leading foot lands hyper extended heel first.

- Arms remain raised forward, maintaining balance and momentum.

- Rear leg is hyper extended for ease when landing. then rotated around the top of the curb.

- Body moves upright.

- Arms wide stabalizing.

- Lead leg still hyper extended it prepares to plant.

- Now steeping normally as he approaches the descent.

- Pace slows on approach.

STEP2: Prepairing to descend

- Steps turn shallow as he slows his motion to move downhill.

- Body position is upright.

- His eyes are forward watching for obstacles or any change in terrain.

STEP3: Descent

- Approaching the incline the user slows his pace.

- Eyes up, he observes the path down making note of any difficult terrain.

- Planning route according to terrain.

Points of interest.

- Arms out and shoulders back maintaining balance.

- Hips back to help slow.

- Knee staying over prosthetic.

- On descent steps stay shallow.

- keeping hip and knee over feet.

"Essentially you're taking small steps with your residual limb, I wasn't moving them very much. You're allowing the prosthesis to take the next stap further"

- On uneven surfaces the user has to calculate for missteps.

- Here he takes a wide step to avoid a fall.

- Hips sit forward keeping it above knee and foot.

- Chest, shoulders and arms sit back adjusting for balance.

STEP4: Stop + Turn

- Slowing Movment started with shallow step to a plant.

- Pivot on planted foot.

- stepping forward with one foot, then reversing with the other.

Points of interest.

- Arms and shoulders on turning side reach back prepping to turn.

- Body Is slowed drastically with deep steps.

- Lead leg plants to prepare to turn.

- Upper half lurches forward to maintain balance.

-Hips sit back, just behind centre point of knee and foot

-left leg prepares to step off into a turning motion.

- Left leg plants as the pivot point.

- Right leg extends fully preparing for next step.

- Body leans to help facilitate turn.

STEP5: Ascent Prep

- Approaching the incline the user Itakes larger step prepelling his momentum.

- Eyes up, he observes the path down making note of any difficult terrain.

- Planning route according to terrain.

STEP6: Ascent

- As he Moves forward, his body angles in order to maintain forward momentum.

- Hips remain over knee and foot.

- Steps begin to shallow upon ascent.

-Arms swing forward.

Points of interest.

- Large steps to start.

- Eyes forward watching for obstacles.

- Body leaning forward.

- Maintaining forward lean propels body forward.

- Wider staggering steps maintains balance.

- Misstep forces the user to adjust.

- Butt sticks out to balance and hcnage angle for leg.

- DEspite butt sticking out, his body is still leaning forward.

- The readjustment lets him step forward.

- His body sits upright to maintain balance.

- His steps during ascent are shallower prior to stumble.

- His bady takes a deep lean forward to push it forward due to stmble slowing him down.

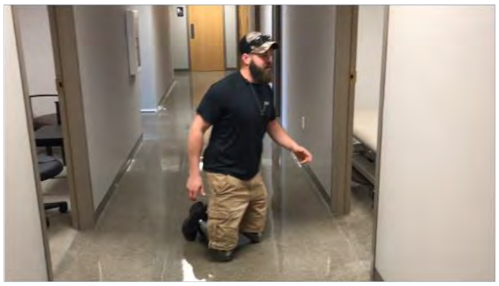
- He is forced to take a widestep to get moving again.

- His steps begin to shallow again.

- Arms and body bob forward and up and down to help push forward uphill.

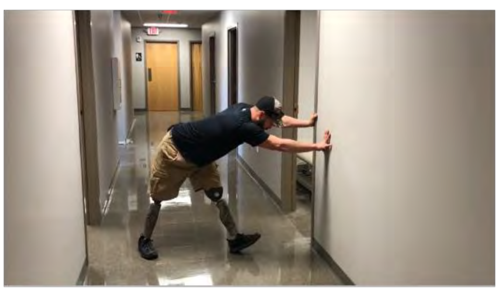
Observing the User Recovering from a Fall

Description:
Double amputee recovering from fall, method 1.

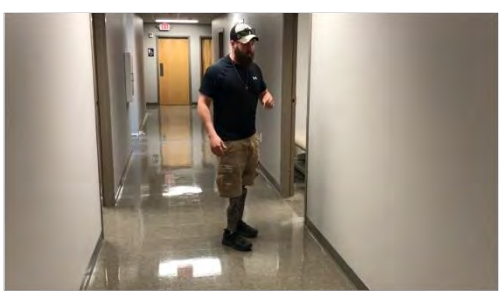


Recovering from a kneeling position the user is required to slide over to a wall for assistence. keeping the knees under the hips.

Supporting himself on the wall the user shifts his weight onto one knee closest to the wall. Then kicking his unspported leg out straight. the user begins pushing himself off the wall. without proper grip on the floor the user will slide and fall.



once he is standing or supporting himself on a single leg, the user is able to straighten the leg that was directly under him. fully extended upper body pushing off wall.



the user has to push is upper body off the wall causing a a balancing act before being upright.

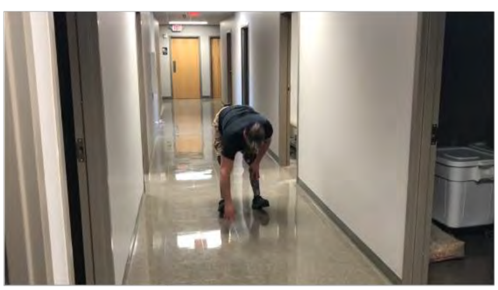
Source: https://www.youtube.com/watch?v=7KILUvJuP-Y

Description:
Double amputee recovering from fall, method 2, view 1.

recovering from a fall without adjacent wall the user positions himself

leaning forward on both hands the user extends one leg.

the extended leg acts as a brace while the user extends the second leg. grip is maintained on the ball of the foot while the user walks his hands backwards.



once his hands are back in a toe touch position, the user walks his hands up his shins and quads to a standing position.

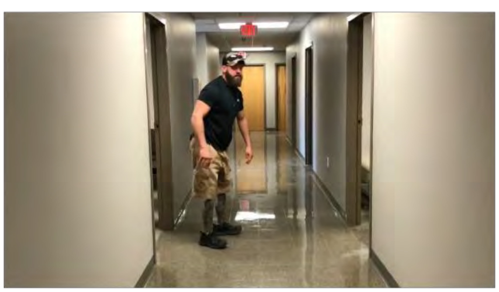
Source: https://www.youtube.com/watch?v=7KILUvJuP-Y

Description:
Double amputee recovering from fall, method 2, view 2.

here we can see how the foot is angled on the instep before twisting it to the ball of the foot. hips up, weight evenly distributed between extended leg and hands.

pushing his hips up, he is able to extend his bent leg to match the already straight leg. pushing his hips up he is able to begin pushing his weight backwards.

hips are set back behind his feet. weight is closer to the centre of the body. hands slowly walk backwards.



as he stands slight adjustments are made in the hips and torso to keep him upright.

Source: https://www.youtube.com/watch?v=7KILUvJuP-Y

Conclusion

Moving through difficult terrain, especially steep inclines, can be an impossible task for most lower-limb amputees. Thought through rigorous practice the user is able to learn how to manage these slopes. Mobility for amputees, regardless of type of amputation or the location in which they are moving through, seems to be a system of managing the bodies balance and momentum. Stopping and starting on a hill where the user is moving upwards is different for amputees. Those without disabilities are able to use the whole leg to propel the weight of their body forward and up. Amputees have to maneuver so they can push their entire body weight up while trying to have their momentum moving in that direction. Walking downward is more natural where they are just managing steps. Balance and momentum play a major role in an amputee's ability to move.

2.1.4 Ergonomics Research (existing Products)

Introduction

Ergonomics of mobility devices for amputees is especially important. The devices are something they will be potentially using for long periods of time. In the case of a prosthesis, it is something that will be connected directly to the user and bear their body weight. The proposed design will take into account important factors such as: where weight is applied, structural support areas, touch points, connecting points, etc. Looking at existing products that aid in mobility will be used as an insight into what manufacturers of these types of products take into consideration when they design for this user group, it will also create an understanding of fundamental features needed, potentially sparking innovation.

Objectives

- Identify ergonomic features of existing products
- Show configurations of current products
- Compare the products
- Identify innovations

Method

Using an internet search for pictures of current related products to show what the components of the design and configuration of components. Various manufacturers were used for research, different types of products related to the thesis topic were used for benchmarking purposes.

Results

The following are current mobility and exoskeletal systems used as benchmarks, and will be examined further for similarities and differences.

PRODUCT 1: EKSO Bionics – Ekso Vest
https://eksobionics.com/eksoworks/eksovest/

PRODUCT 2: SUITX – BackX
https://www.suitx.com/backx

PRODUCT 3: SUITX – PHOENIX Medical Exoskeleton
https://www.suitx.com/phoenix-medical-exoskeleton

PRODUCT 4: Cyberdyne – Lower Limb Type

https://www.cyberdyne.jp/english/products/fl05.html

PRODUCT 5: Cyberdyne –
HAL Lumbar Type for Well Being

https://www.cyberdyne.jp/english/products/bb04.html

PRODUCT 6: INNOPHYS – Muscle Suit
https://innophys.jp/en/product/power/

Product 7: INDEGO – Indego Therapy
http://www.indego.com/indego/en/Indego-Therapy

Product 8: RB3D – Hercules
https://www.rb3d.com/en/exoskeletons/exo/

2.1.5 Safety & Health Research

Health

Immediately after the procedure of amputation, the health of amputees becomes an issue, not to say the health of someone who is expecting amputation surgery isn't important. The reason for the increased health risk is not only due to the recovery from surgery; limb loss, bone deterioration, blood loss, scarring, etc.; rather health is mostly affected by what is happening post-surgery. Despite the high-tech solutions to amputation, prosthetics users eventually find physical effects related to the method of suspending the prosthesis on the residual limb. The environment within a prosthesis liner has the potential to be a hub for bacteria causing; increases skin temperature, sweating, heat rash, blisters, contact dermatitis, abrasions, and even ingrown hair. These skin issues can progress to very dangerous conditions and infections. Furthermore, using a lower-limb prosthesis can lead to issues concerning postural alignment, muscle imbalances and strains, and gait abnormalities. The incidence of back pain among lower-limb amputees ranges around 80%. The residual limb is susceptible to deep tissue injuries from forces due to prosthesis use. Intact limbs of lower-limb amputees are much more likely to develop joint and bone problems such as arthritis as amputees habitually load the intact leg more (LaRaia, 2010).

Safety

Living with lower limb amputation places users at greater risks of falling. Minimizing risks means the awareness of many factors, some of which include; reducing travel over uneven or loose surfaces such as rugs or gravel, observing the path of travel watching for hazards, staying mindful of inclines/declines, clutered spaces, adequate lighting and the use of grab bars. Even tasks that seem simple or mundane such as bathing or using restroom facilities can be extremely dangerous for even the most able-bodied amputees without the aid of grab bars or some form of support (Cristian, 2006).

2.2 Product Research

Introduction

Research conducted on current products related to the proposed thesis topic product is useful because it creates an understanding of what the user is currently using/purchasing, it can also generate an idea of the features and benefits of each product, along with the needs and wants of the end user. Function and performance are important factors in the purchase/use of mobility aids and many products were taken into consideration.

Objectives

- Identifying benefits and features of competing products
- Benchmarking those benefits and features
- Benchmarking material of competitive products
- Benchmark product symbolic, aesthetic, semantic and functional profiles of products
- Examine new products, material, and technologies exploring potential for innovation

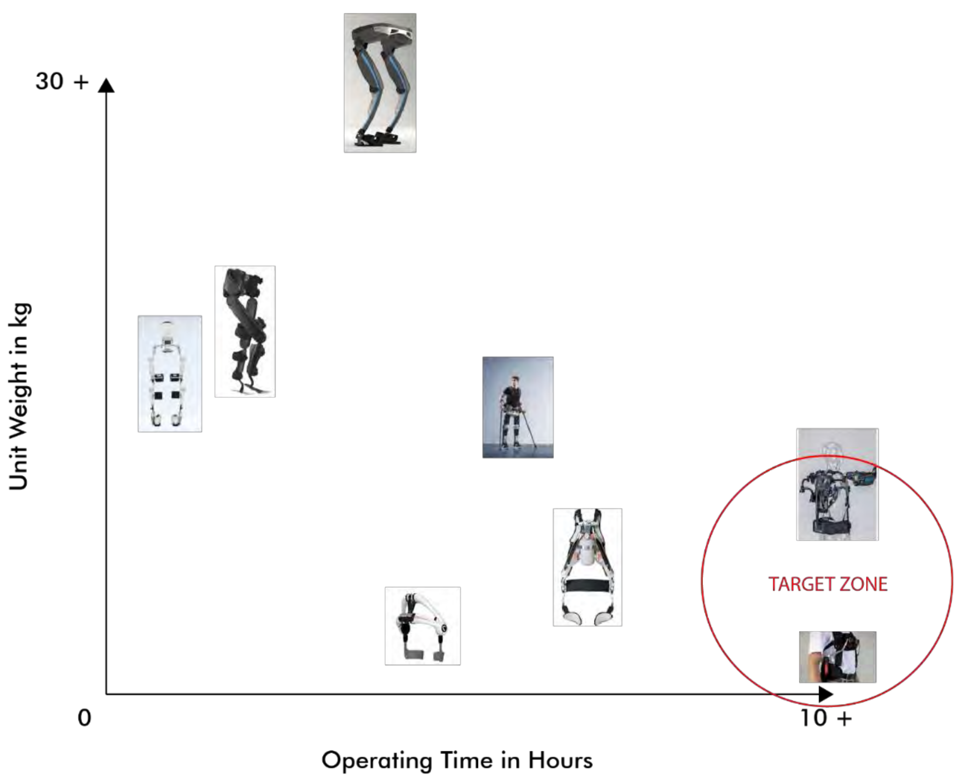
Method

Data and information was gathered to generate a better understanding of current products and their use, this was also done to inform what products were more popular and why.

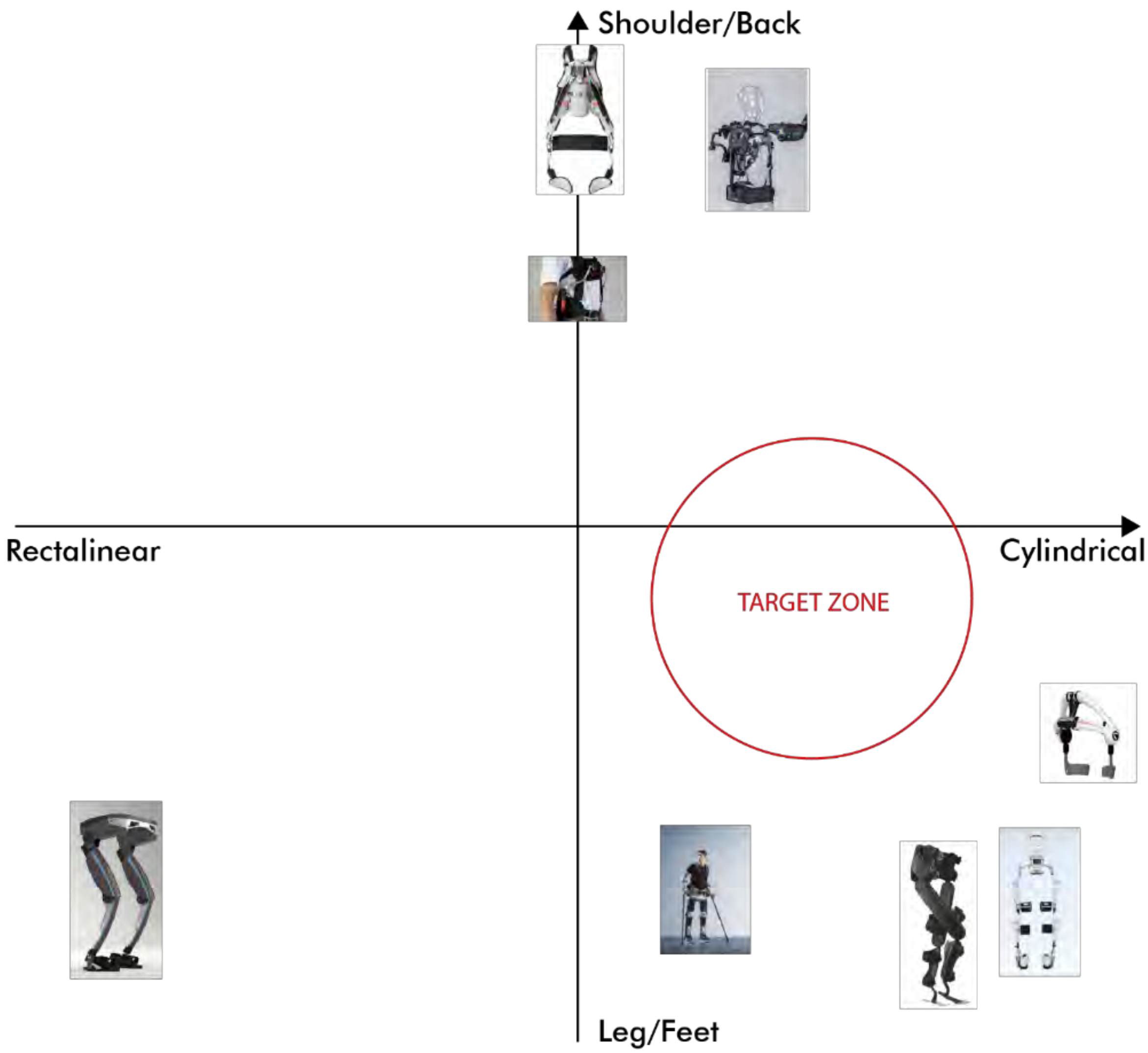
2.2.1 Current Products Profile

Pairs of features were selected to create X-Y graphs. The paired features were assigned to either the X or Y axis, images of each of the comparable products placed on the graph. The intent is to see if patterns emerge which could indicate a zone of opportunity in the market. The first graph compares unit weight to operating time. These were chosen to see if there is any correlation between how heavy the mobility device is and how long they are able to operate for. The second graph compares elements of design and location of contact points. These were chosen to identify if the form is informing the location and or use of each device, and where there might be opportunities for design and market niches.

<u>**X-Y Graph 2.2.1.1:**</u>



X-Y Graph 2.2.1.2:



Benefits, Features

A side by side comparison of key benefits and features, as determined by promotional materials highlighted in the tables below.

Table 2.2.1.1:

Key Benefits of Comparable Products	
1	Comfort
2	Support
3	Reduction of Injury
4	Control/Function
5	Reduction of Forces

Key Features of Comparable Products	
1	Weight
2	Adjustable
3	Power/Rechargeable
4	Assisted Force
5	Modular

Conclusion

- Exoskeletons are a secluded and specialized market due to healthcare aspect and number of companies designing and producing these types of products.
- The first graph shows a pattern where the weight directly affects the operating time. The trick is to design an effective product that is light and has a long time of operation, while still integrating tech.
- Most current products lean towards designs that lend to organics and anthropometrics.
- Current design is clunky and cumbersome
- Products that concern leg support are generally bulky while upper body and more slim
- Opportunity in designing a product that is sleek for both upper and lower body.
- More opportunities may lie in power options and cost benchmarking.

2.2.2 Benchmarking – Functionality

Introduction

Mobility aids and devices that currently occupy the market have many benefits and features for amputees and their ability to be mobile that is becoming more advanced making their means of mobility safer, more controlled and more efficient. Many steps have been taken in the design and production of mobility aids to improve the ergonomics and comfort of these devices. For example, prosthetics now come standards with some form of CPU and gait control device making the device more natural to the user, furthermore these devices can be remotely controlled and adjusted to meet the needs of whatever activities are being undertaken. Mobility aids have many areas of consideration when designing an innovative solution such as ergonomic, comfort, or even location of some components. To understand what the users want/need, or simply why some products meet those wants and needs better than others, a comparison between benchmarked products was conducted; highlighting the key benefits and features of each.

Objectives

- Compare two benchmarked mobility products
- Identify ergonomics
- Identify features

Methods

A comparison was conducted of benchmarked mobility aids. Focusing on touch points, and configuration of components associated with mobility devices. These devices were studied to find what are the most common and useful features and benefits to the user.

Results

A Table comparing the main features for 8 of the 11 comparable products was constructed. The main features chosen for comparison were:

- User Weight Max
- Driving Force (motorized/battery)
- User Height Range
- Assistive Force
- Water Resistance
- Operating Time
- Links with User
- Materials
- Unit Weight

Feature Comparison Table

								
Max User Weight	N/A	N/A	N/A	40kg~100kg	40 – 80kg	N/A	250 lb (113 kg)	60 - 100kg
Driving Force	Non-Powered	Non-Powered	Motorized/ Battery	Motorized/ Battery	Motorized/ Battery	Compressed Air	Motorized/ Battery	Motorized/ Battery
User Height Range	5'0" – 6'4" (152 – 193 cm)	height and waist sizes (5%-95% of human dimensions)	Variable	150 - 200cm	140 - 180cm	*Small/medium* size: 150 cm to 165 cm (4" 11' to 5" 9') *Medium/large* size: 160 cm to 185 cm (5" 3' to 6")	5'1" – 6'3" (155 – 191 cm)	N/A
Assistive Force	5-15 LB. lift assist per arm	Reduces compression on the spine at L5/S1 disc by an average of 60%	speed of 1.1 miles/hour (0.5 m/sec), Vertical support	hip joint: extension 20˚/flexion 120˚ knee joint: extension 6˚/flexion 120˚	hip joint: extension 30˚/flexion 130˚	Back - Up to 35.7 kgf (140 Nm) = 78.7 lbf (103 ft-lb)	Vertical support	allows most trips: walk flat or on slopes up to 10 °, climb stairs, get into squatting or sitting position.
Water Resistance	Yes	Yes	Yes	No	Yes	Yes	yes	yes
Operating Time	Unlimited	Unlimited	4-8 hours	1 hour	4.5 hours	Dependent on use	2 hours	4 hours
Links with User	Waist, back, shoulders, arms	Waist, back, shoulders	Hip, back, shoulders, knees, Shins, Feet	Hip, back, shoulders, knees, Shins, Feet	Waist, Lumbar, Quads	Waist, back, shoulders, Quads	Hip, back, shoulders, knees, Shins, Feet	Hip, Feet
Materials	Nylon, Aluminum, Rubber	Nylon, Aluminum, Rubber	Nylon, Aluminum, Rubber, Polymer (high impact)	Nylon, Aluminum, Rubber, Polymer (high impact)	Nylon, Aluminum, Rubber, Polymer (high impact)	Nylon, Aluminum, Rubber, Polymer (high impact)	Nylon, Aluminum, Rubber, Polymer (high impact)	Nylon, Aluminum, Rubber, Polymer (high impact)
Unit Weight	9.5lb. (4,3kg)	4.9 lb (2.2 kg) and it is worn with an Exoskeleton Harness that	12.25kg (27 lbs)	14kg	3.1kg	4.5 to 6.6 kg (14.6 lb.)	39 lb (17.7 kg)	30kg

		weighs 2.5 lbs (1.1 kg)						

Table 2.2.2.1

Table 2.2.2.2

Design Elements Comparison Table								
								
Overall Form (categories below reflect type of product selected)								
Shape Geometric (Rectilinear, Ellipsoid, Cylindrical etc)	Cylindrical	N/A	Ellipsoid, Cylindrical	Ellipsoid, Cylindrical	Ellipsoid, Cylindrical	N/A	Ellipsoid, Cylindrical	Rectilinear
Repetition Arrays of holes Arrays of lines	Straps/ Supports	Straps	Braces, joints	Braces, joints	Braces,	Braces, Straps, Supports	Braces, joints	Braces, joints
Pattern	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Blue Stripe
Balance (symmetry etc))	Left mirrors Right	Left mirrors Right	Left mirrors Right	Left mirrors Right	Left mirrors Right	Left mirrors Right	Left mirrors Right	Left mirrors Right
Interface Comparison Table								
Buttons / Dials	N/A	N/A	N/A	Soft touch buttons	N/A	N/A	Buttons for Assisted walk	Power
Light indicators	N/A	N/A	N/A	Power/ Battery	N/A	N/A	Buttons light up	Power/ Battery
Touch interface	N/A	N/A	U/I	N/A	N/A	N/A	N/A	N/A
Other	N/A	N/A	N/A	LED screen	N/A	N/A	N/A	N/A

Promotional literature for these products is shown in appendix 1

Conclusion

While the variety of products available is large, most products tend to be cumbersome or limited in modularity. Operating time is low depending on amount of use by user and type of technology implemented. Opportunities exist in making mobility products lighter, smaller, and being less obtrusive. Advancements in tech afford ability to make these products more accurate, modular, stronger, and hidden.

2.2.3 Benchmarking – Aesthetics & Semantic Profile

Introduction

Mobility aids like exoskeletons are easily recognizable products, they still exist in their infancy and are rarely if ever seen in use. Though as technology advances they will become more accessible and commonplace.

Objectives

- Determine aesthetics of exoskeletons and prosthesis
- Identify what the design language of prosthesis is
- Understand why users buy and use the devices they do.

Method

Research was conducted through interviews to determine why a user may buy specific devices as well as a comparative product research report. Personal experience was reflected on to understand aesthetics and semantic profile of exoskeletons and prosthesis.

Results

Mobility devices such as exoskeletons and prostheses are easily identifiable due to the nature of their use as mobility aids for those who have had an amputation of a major supporting limb. Prostheses' are typically constructed with a main housing; in a lower limb prosthesis this would be the lower section of the leg including the shin and calf. This main body contains a CPU, motor, and gyroscopes which is the brain behind the gait control. Attached to the lower portion of the body is the foot, which come in many configurations and styles, some have built in shock absorbers for a smooth gait, others are build for performance like the blade foot seen used by athletes. Connected to the upper portion of the main housing is the knee joint controlled by the interior components, and the socket. The socket is considered the most important component because it is the connection between user and tool. An ill fit can cause abnormalities in gait, and thus cause further health complications. A perfect fit can leave the user feeling as if they never lost their leg.

Exoskeletons vary in size and use, the mainly consist of joints, supporting structure, anchors, servos, gyroscopes, a CPU, and some sort of power source. There are unpowered units as well. Prostheses' are a combination of form and function, the user wants to be able to get the best most natural, reactive performance out of their device; however, due to the nature of limb loss the styling of these devices are also important. Having something natural looking while still durable is a very important semantic to consider.

2.2.4 Benchmarking – Materials & Manufacturing

Introduction

The material considerations when designing for mobility aids are important because of the nature of the device. They need to be strong enough to withstand the abuse of daily continual use, light enough not to wear out the user, and comfortable because of the direct contact to skin. The materials and forms will guide and inform the manufacturing methods, though the most sensible methods possible should be sought out.

Objectives

- Identify materials used in existing prosthetics
- Identify best possible manufacturing methods

Method

Research was conducted in current materials and manufacturing methods in order to have a deeper understanding of the development of prostheses.

Results

Materials

Currently prosthetics are taking advantage of strong light weight materials such as aluminum, connected to a carbon fiber socket mold containing a silicone socket liner. Since the very first-time mobility came into question due to amputation, the goal has remained the same, but now the methods in which people are fulfilling those goals is changing. Materials and computers are becoming more advanced allowing manufactured to push the limits of what their devices can do. The introduction od CPU controlled gait has dynamically changed the possibility for the end outcome of what a mobility device can be and how they are operated or respond to the human body. Doctors are now experimenting with limbs that are controlled externally with neuro connections, allowing the device the understand the signals the brain is making and respond to the accordingly, thus changing the landscape of current materials used (Rajak, 2015).

Manufacturing

The manufacturing process for prostheses is much like any product, where standardized components are made in bulk in a factory, then sent out to the manufacturer's distributors. The key difference with prosthetics is that each device is made to order and completely custom. When the parts reach the end user, they have been assembled to fit him/her in the best possible way. Furthermore, the connection point, the socket, is completely custom. Without a custom construction for the socket the user would have difficulty moving or feel burdened and clunky.

2.2.5 Benchmarking – Sustainability

Introduction

This section of the thesis report covers and contains the sustainability initiatives that benchmarked products and companies have taken to better their product and impact globally.

Objectives

- Determine benchmarked sustainable features to this thesis report
- Determine sustainable features to incorporate into the concept

Results

Many manufacturers of mobility aids consider sustainability when designing and producing their products. As mentioned in section 2.2.4 Materials and manufacturing of this thesis report, materials for use in prostheses are heavily considered. Furthermore, one of the focus' of sustainability for these manufacturers is not just material consideration that may be difficult to implement into current manufacturing processes, but also the production of more durable products that will stand the test of time and the daily use that these products see. Currently materials such as aluminum and carbon fiber are used for the majority of the structure due to their light weight and recyclability. However, the manufacture of both these materials can be costly, and in the case of carbon fiber, there is a very low rate of recyclability. This material consideration is of course offset with durability and lifespan meaning less product is being made.

2.2.6 Interview Results

Introduction

This section of research involves the interviewing of amputees and therapists that work in rehabilitation of amputees. These interviews were conducted in a loose manner as to promote natural discussion and the floe of conversation. This helped gain insight into the thoughts of the daily user, their needs, and how they use their devices creating a deeper understanding of the problems involved and potential for design innovation.

Objectives

- Connect with users and therapists
- Understand frustrations and problem areas with mobility devices
- Ask question related to the topic
- Understand the needs of the user
- Sum up finding and uncover results

Methods

Interviews were conducted with multiple amputees to ask question regarding life as an amputee, from the moments leading up to amputation to life as it is now. The three users' interview are a man living with bilateral amputation since childhood, a man who recently lost a single leg from cancer, and a man who lost his legs and an automobile accident resulting in a bilateral amputation. Interview transcripts can be found in appendix I.

Results

The information gathered can be summed up as follows;

- Average age of amputee's ranges from mid-30's to mid-40's
- Mobility hinges on their devices
- Mobility includes: walking, running, climbing, hiking, athletics, inclines, steps, pushing, pulling, working
- Devices are used for prolonged periods of time (13+ hours)
- Devices include: wheelchairs, prosthetics, crutches, canes
- Using devices for long periods of time can be a catalyst to long- and short-term health complications
- Users want more intuitive devices
- Users tend to be happy with devices because of their return to 'normal' life
- Users want a device that will take a beating, will continue to work, and is easily maintained
- Users don't care if the look is wild or blue sky as long as the function meets or exceeds the users' needs
- Like the idea of modularity
- Like that they can control their device settings from their phone

CHAPTER 3: Analysis

3.1 Needs analysis

Mobility is a priority concern and vital need to lower-limb amputees. Research results in previous chapters shows that, mobility is a purposeful action that amputees have an extreme degree of difficulty without the aid of some form of mobility device. Various forms of devices are implemented by various users in order to ease the strain of moving through space without the use of a major supporting limb. This thesis focuses on amputees who spend upwards of 13 hours a day using a prosthesis. A prosthetic limb, so far, is the most advanced and natural method of providing mobility for lower-limb amputees. Amputees have to be able to be able to walk as naturally as possible, in an efficient manner, safely, and without strain. Therefore, designing a mobility implement for lower-limb amputees that addresses the needs above allowing them to return to “as normal as possible” quality of life if not better prior to amputation. Previous chapters showed research multiple areas of influence. This chapter will analyze and discuss the results of research concerning user needs.

3.1.1 Needs/Benefits met by current products

Introduction

With a large variety of mobility aids available on the market, with various levels of usability and ergonomics. This section will aim to discuss the users’ needs and how current products meet them, and suggest improvements for the final design proposal.

Objectives

- Identify the users’ needs

- Identify the needs that are met
- Identify unmet needs
- Identify areas for improvement

Method

This section reflects on the user profile, current user behavior, features and benefits, and the user interviews. A needs report was written to investigate the users' needs of current products related to mobility. Product research was also conducted in order to gain an insight into how users perceive current products. Findings from those reports are as follows.

Results

Many current mobility devices are trying to meet their users needs, though they have been relatively successful, many ergonomic and user needs are not being addressed. The following is a list of potential areas in which mobility aids can be improved on.

- Comfort/Ergonomics
- Safety
- Ease of use
- Control
- Maintenance

A mobility device for amputees that ensures their safety while affording them comfort and the ability move effortlessly in any environment.

Two Products close to the 'design opportunity' on graph 1 (appendix II) were assessed and compared on how they met customer needs. The two products selected were:

1. EKSO Bionics – Ekso Vest
2. SUITX – BackX

Results are seen in the table below. Benefits are identified for this product based on previous sections. Possible niche markets are deficits in current product offerings.

Table 3.1.1.1

Features	Features Comparison		
	EKSO Bionics – Ekso Vest	SUITX – BackX	Possible Niche Market
Weight	Good	Great	
Adjustable	Good	Good	
Power/Rechargeable	Poor	Poor	X
Assisted Force	Fair	Poor	X
Modular	Poor	Fair	X

Features	Benefits Comparison		
	EKSO Bionics – Ekso Vest	SUITX – BackX	Possible Niche Market
Performance	Poor	Fair	X
Productive	Fair	Good	X
Power/Rechargeable	Poor	Poor	X
ease	Poor	Fair	X
comfort	Fair	Good	X

Discussion

The Benefits and Features comparison table 3.1.1.1 shows areas that should be considered for improvement for this thesis project. Improvement of these areas will set the proposed product out from current products in the market. These tables outline the users needs and how they are being met. Most current products are good in a few areas leaving the others to fall behind.

3.1.2 Latent Needs

Introduction

User needs are the foundation to any good design solution, especially when ergonomics, quality of life, and other human factors are concerned. The final proposed solution is a product that is aid in the mobility, safety, and comfort of its user; furthermore, it must be able to meet the fundamental human needs of that user. In this case the mobility device is a piece of equipment that allows its user to move efficiently through space without impediment or pain from the residual limb caused by amputation, and will need to be able to perform consistently in order to meet those needs. This section will focus on the latent needs of the user to understand which are and are not being met.

Objectives

- Identify latent needs
- Understand needs being met
- Discuss how the product responds to user on a fundamental level
- Discuss how proposed solution will meet those needs

Method

This section reflects on the user profile, current user behavior, features and benefits, and the user interviews. A needs report was written to investigate the users' fundamental human needs of current products related mobility. this section also refers to Maslow's Hierarchy of needs in order to better understand fundamental needs and how they are being met.

Results

The following illustrates the relationships between the product and fundamental human needs, with reference to Maslow's Hierarchy of needs.

- **Comfort** in this context is increasing the mobility experience for amputees by adding a level of comfort where there is discomfort in lower-limb amputation. This includes mobility through indoor and outdoor environments, with freedom to move safely. Comfort also includes the harshness of the ride or movement (ride harshness would contribute to a feeling of a *loss of control*, increasing possibility of injury (risk), both of which decrease one's sense of protection)

- **Security** is the major fundamental human need met.

- **Style** is an important expression of individuality. What is considered by the group as stylish
increases **self-esteem**, in this context improving mental state for those who recently lost a major limb.

- **Efficiency** is defined as the effort required to perform at a particular level. This is related to **control** the user has during the activity (**autonomy**)

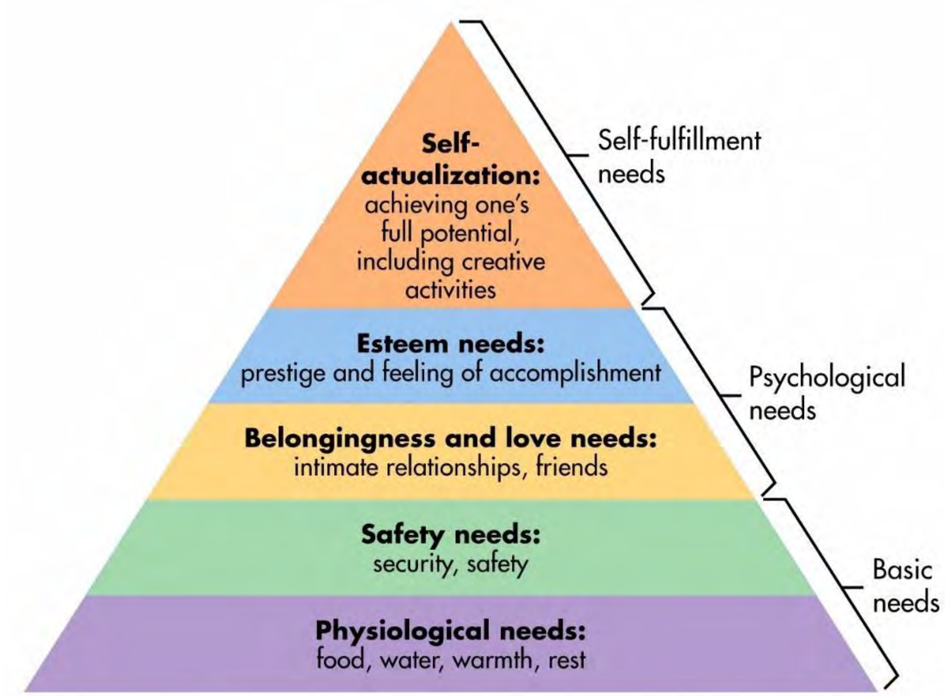
- **Ease** is in many ways related to efficiency in terms for fundamental human needs (i.e. **control, autonomy**).

- **Fun** related to **leisure** ('travel' to new interesting environments) and **belonging** (**shared fun, participation** between infant and caregiver). In this context helping amputees return to as normal a life as possible.

<u>Table 3.1.2.1</u>

	Benefit	***Possible Corresponding Fundamental Human Needs (FHN)***	***Relationship between Benefits and FHN***
1	Comfort	Control, security, self-esteem (mastery)	strong
2	Style	Esteem, belonging, aesthetically pleasing	moderate
3	Efficiency	Accomplishment, autonomy, self-esteem	strong
4	Ease	Accomplishment, autonomy, protection, security, control, self-esteem (mastery)	strong
5	Fun	Leisure (excitement), Participation, Belonging (shared fun)	strong

(FHN – Fundamental Human Needs)



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0-1Retrieved from http://www.21stcentech.com/wp-content/uploads/2011/10/maslow.jpg

Discussion

Mobility of those with disabilities, namely lower-limb amputation is a purposeful activity based on ease of functioning, increased safety, and comfort afforded to the amputee. Amputee mobility is a social activity, since the ability to be mobile improves the user's ability to move through all environments allowing for interaction on the journey. Esteem can be afforded by good styling/quality cues of the device. Control and mastery of the device is related to the performance of the machine but and the comfort it affords the user.

3.1.3 Categorization of Needs

Introduction

After the needs and how they relate to the user have been stated, the information must be categorized into groups allowing for clear and simple understanding of the working data. These groups will create an understanding of which needs are a priority regarding the final design solution. This in turn will help create a definition and recognition between user needs and user wishes, further prioritizing the needs.

Objectives

- Determine needs vs wishes
- Determine immediate needs
- Determine latent needs
- Discuss categorization of needs.

Method

User needs and wants were determined through a process that included; user interviews, observations, surveys, and product research. This section also reflects on the user profile, current user behavior, features and benefits, and the user interviews; it also calls back to the initial needs report written in order to investigate current products and how they meet users needs/wishes. The defined needs were categorized into three groups; user wishes/wants, immediate needs, latent needs.

Results

The final design solution will focus on ergonomics, safety, and efficiency. Improvements in these three areas will have a dramatic effect on product usability, quality of life, and health risks associated with prosthetics. The categorized user needs are as follows:

Immediate needs

- Natural feel when walking/gait
- Less exerted energy/less tired
- Low probability of loss of balance/misstep
- Reduced pressure on residual limb

Wishes/Wants

- Comfort while wearing device
- Improved mobility
- Health risk reduction
- Easily donned/doffed
- Discrete, natural styling

Latent Needs

- Comfort/ergonomic
- Safety
- Ease of use
- Higher level of control
- Easy maintenance

Discussion

The defined needs are categorized and ordered in priority looking at the user's immediate needs, wants, and needs to be met after those are met. These needs will play a major role in the decision of the final design solution.

3.1.4 Needs Analysis Diagram

Introduction

The section uses information taken from the categorization of needs in order to demonstrate how the final proposed product will meet the needs and wants of the user. The desirability, viability, and feasibility of prostheses/mobility devices for amputees will be discussed in order to achieve a deeper understanding of how the proposed product will affect the user. These characteristics will be the basis for innovation which will set the final proposed product apart from currently existing products.

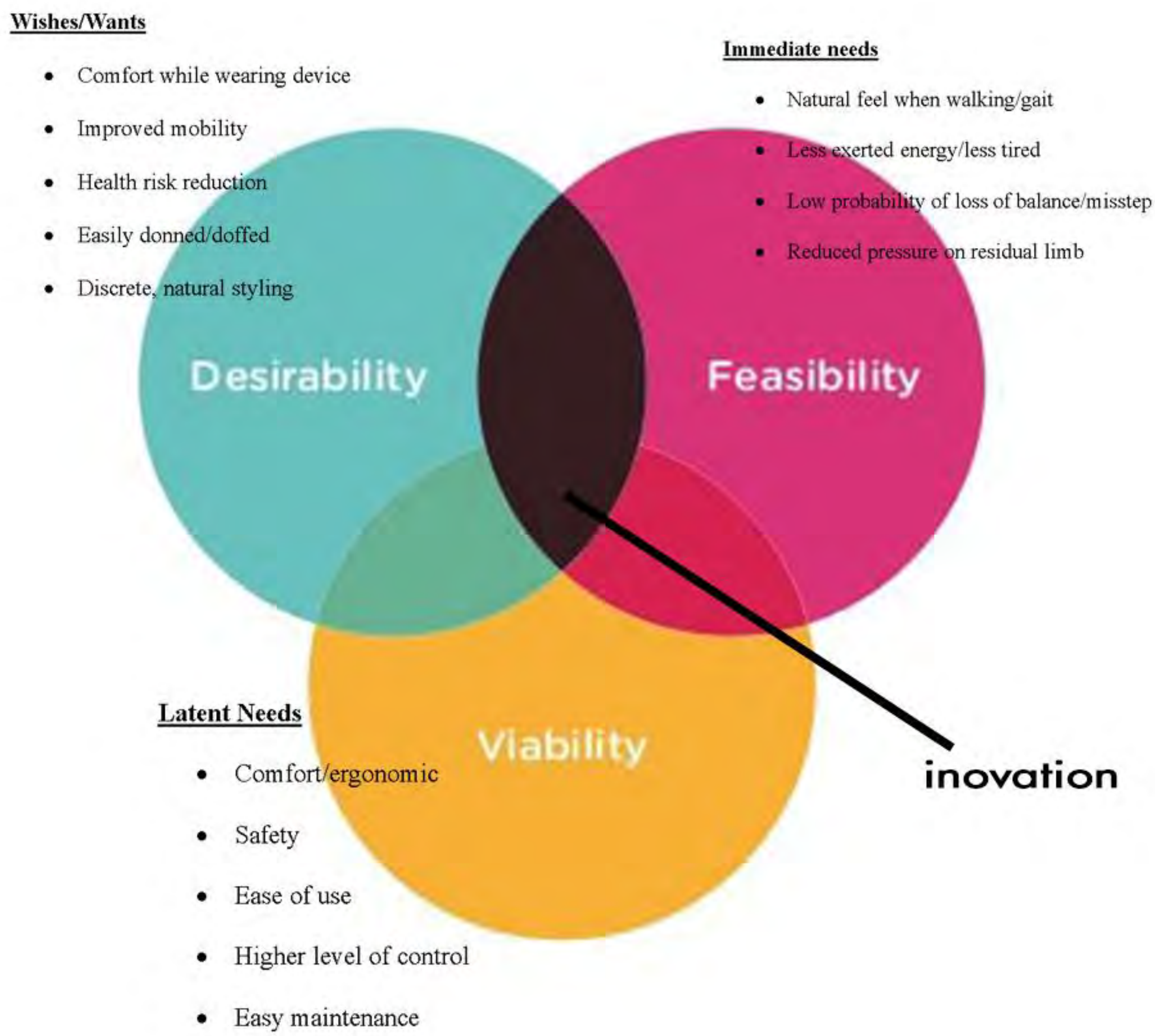
Objectives

- Understand the desire of mobility aids
- Produce evidence to the user
- Provide a feasible option for the user
- Innovate

Method

This section reflects on all previous sections including the user profile, current user behavior, features and benefits, and the user interviews, aesthetics/semantics.it will also call back to information gathered and categorized in the 'categorization of needs' section in order to complete a to this section creating a deeper understanding of innovation potential. This section utilizes a chart for finding successful human centered design following, where the needs categorized needs were implemented into the following characteristics; viability, desirability, and feasibility.

Results



Retrieved from: 3.1.4.1 Finding Successful Human Centered Design

Feasibility

Feasibility of mobility devices for amputees relies on where or not the devices aiding in mobility fulfills the immediate needs of its user in the most impactful and least obtrusive way possible. Outlined in previous sections, these are shown to be what is priority to the user. The need to have a natural/improved gait, less exerted energy, low probability of misstep or fall, and reduced pressure on the residual limb are important needs to be addressed by this thesis project. If these needs are met by the final design then it can be considered feasible.

Desirability

A desirable product in terms of mobility aids, is one that will meet the users wishes and wants. The design of a mobility device for amputees must infer reliability, reliability means that it fulfils the requirements of the wishes and wants set out in previous section. If the final proposed product satisfies the wishes and wants of the user it can be considered desirable,

Viability

The finale design proposal must be viable for the end user environment. This means previously stated latent needs require fulfilment in order to considered viable. Users will need to know how the final product stands up to other products and why it is more successful in those areas. A successful design solution will meet or exceed latent design needs and push innovation.

Discussion

Innovation id the byproduct of all three characteristics meeting fulfillment in a complete and cohesive manner as seen in the Venn diagram displaying needs and characteristics. The final design solution will aim to reside in the middle of all three characteristics

3.2 Functionality

3.2.1 Activity/Workflow Mapping

Table 3.2.1.1: Simplified User Observation

	1. Assessment users pace slows as he approaches the incline. taking care not to make a careless step. Planning route if there are obstacles
	2. Moving down the user accepts his weight on the heels of his prosthetic, driving the edge of the foot into the ground allows for the shoe to dig in creating a stronger contact point.
	3. Moving up (start) the user approaches the incline normally, as the incline steepens he leans forward compensating for the inability to adjust his feet, knees, and hips together.
	4. Moving up Drastic Incline the user here is seen having to drastically adjust the abgle of his upper body in order to make his way up the incline. keeping his foot and knee directly under his hips.

Discussion

For thorough user observational research of prostheses in use, please refer to section 2.1.3 Activity Mapping. Frustrations and weaknesses in current designs seen throughout the process are exposed in each step as mobility weaknesses. The weaknesses are as follows:

- **Slowed pace**
- **Small steps**
- **Limited control of prostheses**
- **Route planning**
- **Hard impactful stopping on residual limb**
- **Rotational pivot on prostheses**
- **Breaking posture for balance**
- **Large steps begin motion**
- **Limited control of foot/ankle**

3.2.2 Activity Experience Mapping

Introduction

Previously in chapter 2, the activities of the user were researched in order to understand how they interact/use current mobility devices. This section will use the research from chapter 2 and section 3.2.1 in order to generate a map of the users experience during those activities, and whether they are positive or negative.

Objective

- Identify negative user experiences
- Identify positive user experiences
- Map out the user experiences
- Set a goal for the desired user experience

Method

This section relies on research found in chapter 2, which used a report found in the appendices conducted to map the user experience during activities observed. The key activities and potential improvements are highlighted in the tables below and discussed further. The areas for potential improvement will be considered when designing the final proposed product.

Results

Moving through difficult terrain, especially steep inclines, can be an impossible task for most lower-limb amputees. Thought through rigorous practice the user is able to learn how to manage these slopes. Mobility for amputees, regardless of type of amputation or the location in which they are moving through, seems to be a system of managing the bodies balance and momentum. Stopping and starting on a hill where the user is moving upwards is different for amputees. Those without disabilities are able to use the whole leg to propel the weight of their body forward and up. Amputees have to maneuver so they can push their entire body weight up while trying to have their momentum moving in that direction. Walking downward is more natural where they are just managing steps. Balance and momentum play a major role in an amputee’s ability to move.

Table 3.2.2.1: Key Activities

Major Activity	Description of major activity	Steps (point form)
Key Activity 1: Walking Down hill	The user prepares for his descent by observing and analyzing the terrain. He approaches the incline and makes small steps allowing the prosthetic to take the next step. He is mostly maintaining balance and momentum while moving.	Slow motion down
		Take smaller steps
		Adjust balance to allow for next step
		Control momentum
		Adjust for obstacles
		Prepare to slow or stop when needed
Key Activity 2: Stopping and Turning	The user slows his pace, then takes a couple of longer strides slowing him down dramatically. He plants one foot to act as a pivot. Then takes a rotating step. The pivot foot then moves back. Turning him 180 degrees.	Slow pace from descent
		Stopping strides
		Prepare to turn.
		Plant pivot foot.
		Adjust body for turn and slow, controlling momentum.
		Take necessary steps in order to turn
Key Activity 3: Walking uphill	Increased stride at the beginning portion, this causes his to speed up. Forward motion allows the ascent to be easier. As hi approaches the incline the steps become shallower and quicker keeping him going forward. His body angles and his arms pump forward slightly giving him a forward motion.	Speed up with larger steps
		Maintain balance and momentum forward
		Adjust steps to short and fast
		Prepare to stop or slow
		Arms bob to help with momentum
		Maintain forward motion to the top

Table 3.2.2.2: User Experience Map

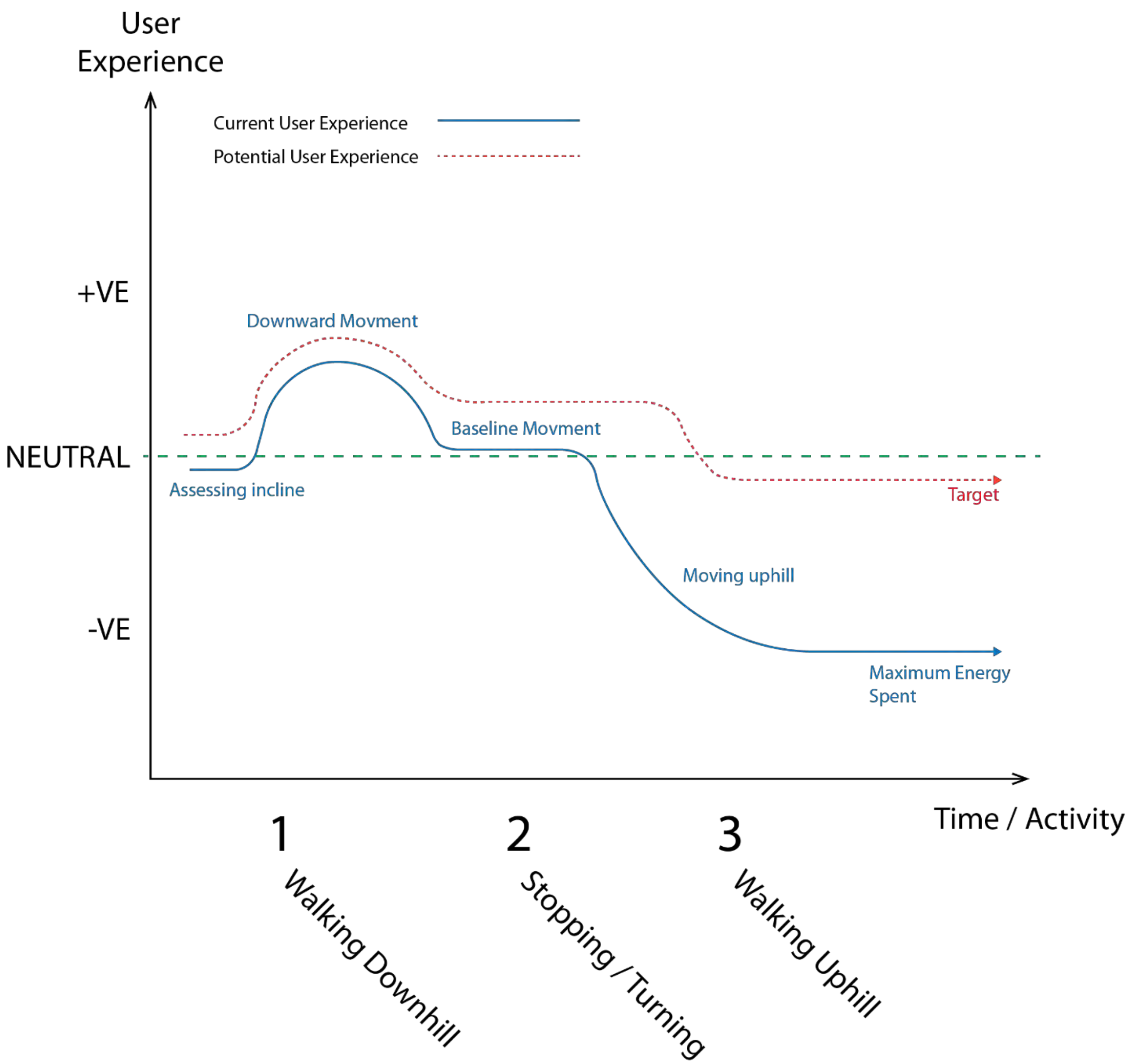


Table 3.2.2.3: Potential User Experience Improvements

	Steps		Base User Experience	Potential User Experience
Key Activity 1 Walking Downhill	1	Slow motion down	Slowing, being careful, not a lot of effort exerted, watching for obstacles, takes a bit more time.	Reduced Balance control, letting user focus on managing steps.
	2	Take smaller steps		
	3	Adjust balance to allow for next step		
	4	Control momentum		
	5	Adjust for obstacles		
	6	Prepare to slow or stop as needed		
Key Activity 2 Stopping and Turning	1	Slow pace from descent	Minimal effort, takes technique, used regularly not even on inclines,	Reducing how long / hard strides are needed to stop or turn
	2	Stopping strides		
	3	Prepare to turn		
	4	Plant pivot foot		
	5	Adjust for turn and slow, controlling momentum		
	6	Take necessary steps in order to turn		
Key Activity 3 Walking Uphill	1	Speed up with large steps	Maximum effort exerted, fall can be dangerous, difficult to get feet up hill, difficult to continue momentum forward,	Making forward momentum easier, user focusing on steps rather than having to lean for momentum.
	2	Maintain balance and momentum forward		
	3	Adjust steps to short and fast		
	4	Prepare to stop or slow		
	5	Arms bob to help with momentum		
	6	Maintain forward motion to the top		

Discussion

users were observed in two different locations performing various tasks while moving through space and moving strictly in extreme conditions like sharp inclines and declines. The users were observed moving using various mobility devices, informing changes in mobility that may or may not depend on device.

Some observations made that will inform design include; the users need to lean on objects maintaining balance in order to perform tasks that require manual dexterity, the users high level of adaptability not only to what kind of surface they are walking on but also their ability to adapt depending on device used, and the users explicit need and desire to be able to maintain balance. Amputations of lower-limbs, no matter how minimal or sever they are, directly affect balance which seems to be the key factor in providing stable, safe, and confident mobility. In future observational information gathering, participants would be asked before, during and after tasks how they feel about said task. Allowing them to express their thoughts about their ability to perform may raise more questions or evolve in to other task requests which could lead to new design solutions or insights.

3.3 Usability Ergonomics

Introduction

Movement through an environment for most people is done with minimal effort, planning, or even thought. Living with an amputation, specifically a lower-limb amputation, changes the dynamic of movement and mobility through environments dramatically. While amputation may be a lifesaving procedure, the resulting impact of amputation can be lifechanging, presenting the individual with adjustments in almost all aspects of daily living and functioning. The dramatic change of having amputation of a major limb changes how the human body performs tasks and adapts to them, causing irregular strain to the body (Cristian, 2006).

These adaptations amputees develop for themselves are of significant importance and require attention due to the eventual outcome being associated health risks including musculoskeletal disease, gait abnormalities, hip displacement, residual limb pain, and spinal deformity (LaRaia, 2010). Amputation rates have not decreased over the last decade, in fact the incidents of lower-limb amputation are projected to double by 2050 (Imam, 2017). These factors have important implications for the future of personal, social, health care concerns regarding amputees and their rehabilitation.

This problem encompasses the full body interaction and ergonomics to help amputees. Improving their safety, comfort, control, and more so their ability to move through environments with less effort exerted. The resulting proposed product would be lightweight, modular, and accommodating to the fit of a wide range of body types.

Literature Review

When considering the ergonomics of lower limb amputees and the mobility associated with it, including quiet stance, many factors had to be considered and included specific touch points of the human body. During quiet stance and episodes of locomotion, the body acts as an inverted pendulum; balance of the body is all controlled from the feet up. Quite stance is continuously being monitored and adjusted at the ankle at a forward and backward motion, while the hips adjust from left to right. As the locomotion on the travelled surface becomes more aggressive or violent, more of the body has to be involved (Winter, 1995). We are inherently unstable systems due to the fact the two-thirds of our body mass is located two-thirds of body height above the ground.

Ergonomics for the proposed mobility device have to consider not only the location of implements connected directly to the body for enhanced locomotion; but also allowing for the best possible freedom of motion as to not constrain the user and limit their ability to move freely. Another consideration should be the loss of haptic information and stretch reflex due to limb amputation, and how to implement or reincorporate that information to the spine. The rove and reach of pelvic, knee, ankle, and even trunk/bending of the trunk are not spherical in nature, rather their arcs are complex and may extend past dimensions described in “The Measure of Man & Woman” (Tilley, 2002). The extension of limbs to their extreme will be a consideration for the proposed thesis project due to the nature of locomotion: initiating and terminating gait, turning, avoiding obstacles (altering step length, changing direction, stepping over obstacles), bumping into people and objects, and recovering from missteps.

Methodology

Ergonomic evaluations of current mobility devices as well as observational analysis and literature reviews were conducted in order to gain insight into the users’ habitual touchpoints, what are potential areas of improvements, and the important ergonomic considerations for amputees and the locomotion associated with them.

Objectives

The purpose of this process is to evaluate and understand the challenges of mobility/ locomotion concerning full-bodied human interaction design and full-bodied ergonomics. This report will focus on three major body part areas relevant to thesis criteria and full-bodied human interaction design. This report will be used to assess the three major body part areas in relation to human factors, ergonomics, ease of use, and quality of life.

Decisions to be made

- Existing concerns of amputee mobility
- Touch points of current mobility aids
- Types of locomotion and the aids associated with them
- Effects of amputation on locomotion
- Loss of haptic senses / stretch reflex due to amputation

The following full-bodies human interactions related to the three major body parts were investigated in order to improve mobility, locomotion, and quality of life:

- Donning and doffing mobility aids
- Initiating, terminating, and travel of gait
- Interaction of prosthesis and residual limb, and the effects of sensory stimuli loss

Users Targeted by Product

The target demographic are individuals who have suffered above knee and below knee amputation due to trauma and or health complications. Their age ranged from 30 to 60, predominantly male with a small population of woman. Due to high number of traumatic events related to amputation, race, income and education did not play a major role in the demographics associated with amputation. The user will be spending upwards of 13+ hours using the proposed device (O&P EDGE patient survey, 2011).

Evaluation Process

As a part of the design process, a full scale (1:1) ergonomic buck was built using rudimentary materials in order to gain insight into the various touchpoints associated with the proposed thesis project and allowed for the critical observation of the following:

- Observing donning and doffing strategies
- Observing the ability of the body to move in device
- Documenting and strategizing touchpoints/connection methods
- Identify dimensions related to the user in the device and the potential need for them to change depending on the user

Description of User Observation Environment used in study

Date of observation: January 2nd 2020

Location of observation: Residence in Kitchener Ontario

Results

The locomotion of the human body is an active, dynamic event in which the body is constantly subconsciously adjusting to the environment and how it is overcoming obstacles, elevation change, and change in direction. As a result of the dynamic nature of mobility specific pivot points associated with mobility must accessible to the user and allow for freedom of motion while offering support to the musculoskeletal system.

Furthermore, the body during moments of quite stance must be allowed the freedom of motion in order to achieve maximum balance efficiency. Without the haptic response/information from one or even both legs, balance and locomotion become a difficult task. Virtually all neuromusculoskeletal disorders result in some degeneration in the balance control system (Winter, 1995).

The aim of the proposed product is to enhance the mobility of amputees by restoring some elements of haptic response and stretch reflex, while contributing to the support of body post lower-limb amputation and allowing the offering enhanced mobility through the combination of ergonomic factors associated with the support structure and full-body human interaction.

The first of three major body part areas focused on is the legs. The proposed device must fit onto the residual limb comfortably and snuggly without impeding the users' ability to move in regards to reach and rove of the knee/hip. The balance of the body during quiet stance and bouts of locomotion are likened to an inverted pendulum. The peripheral unit must not combat the intact leg and work with it so the user does not feel the need to load it during moments of quiet stance. Furthermore, this section must allow for control and stability in its ankle region giving a natural feeling to balance.

With the loss of lower limb information balance becomes stunted, having some form of haptic sensor in the upper leg area will be necessary. Three major components of the leg dimensions will have to be considered for this to be effective: foot to ankle, ankle to knee, and knee to hip. The most important one being knee to hip. Secondary dimension to consider are the thigh link dimension for knee flex and thigh measurements which will have to be considered for donning/doffing and over all fit of the supporting structure for the lower limb. This area is considered the first section that related to and adjust balance in the body.

The second major area of the body to be focused on, and potential the most important is the hip. The hip acts as the main connecting body from leg to trunk. Without a proper connecting point or support the user will gravitate to loading the existing leg causing potential health risks. Some main dimensions to focus on in the area are: hip sit, lumbar height, abdomen, ischia, and pelvic links. This section is the secondary section that adjust for balance.

The third and final major area of the body focused on is the trunk/spine. The trunk and or spine act as the main component of support in the upper body. The connection from the hip to the trunk will act as main section in promoting balance and support for the prosthesis and residual leg, transferring forces from those areas to the this stronger more central area. Some main dimensions that will be considered here are: lumbar height (in conjunction with the hip area), waist, chest, shoulder height, cervical link, shoulder width, abdomen. This section is considered the third section that adjust for balance.

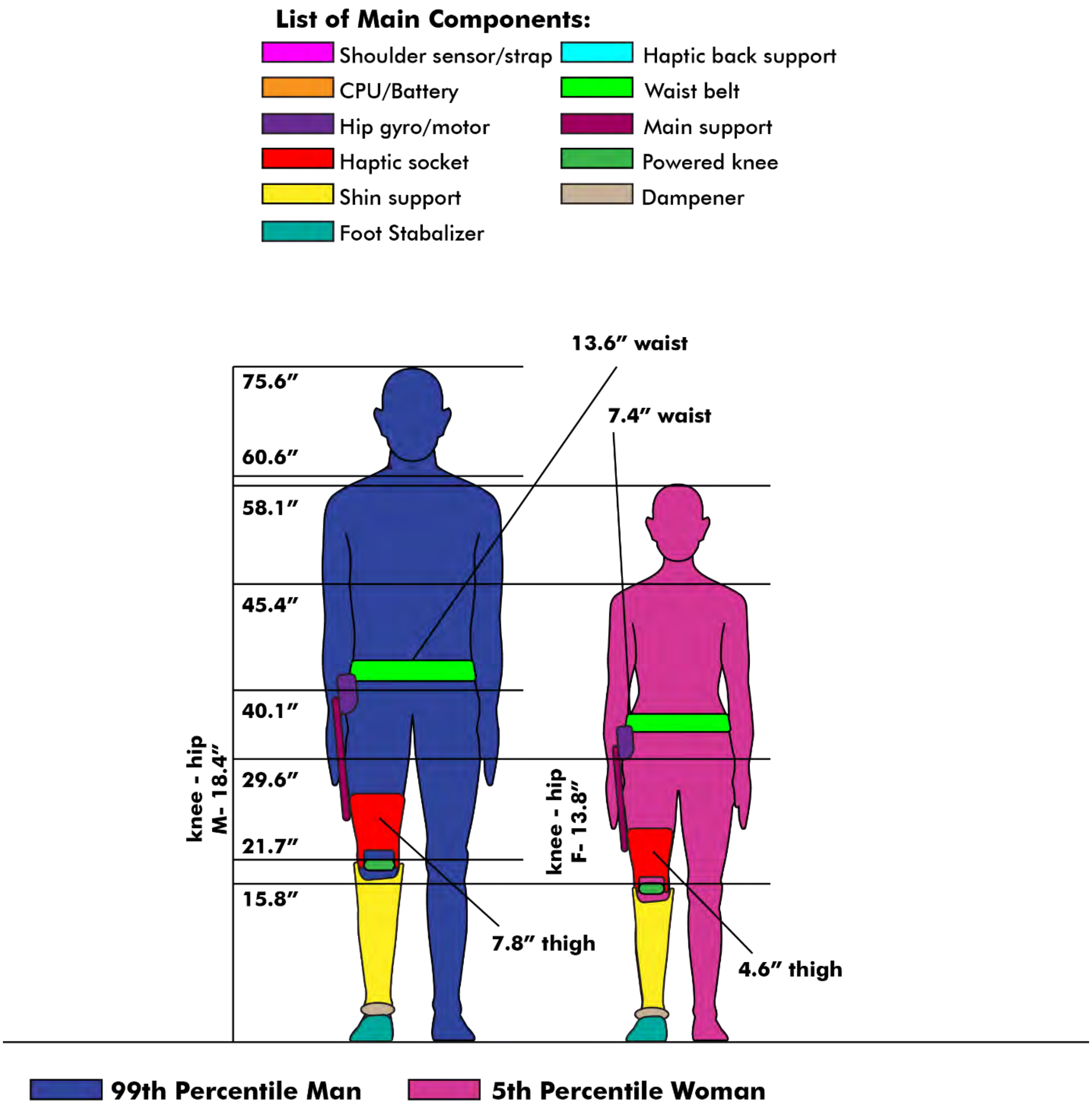


Figure 0-2: 99 percentile man & 5th percentile woman, with related dimensioning as seen related to potential mobility device.

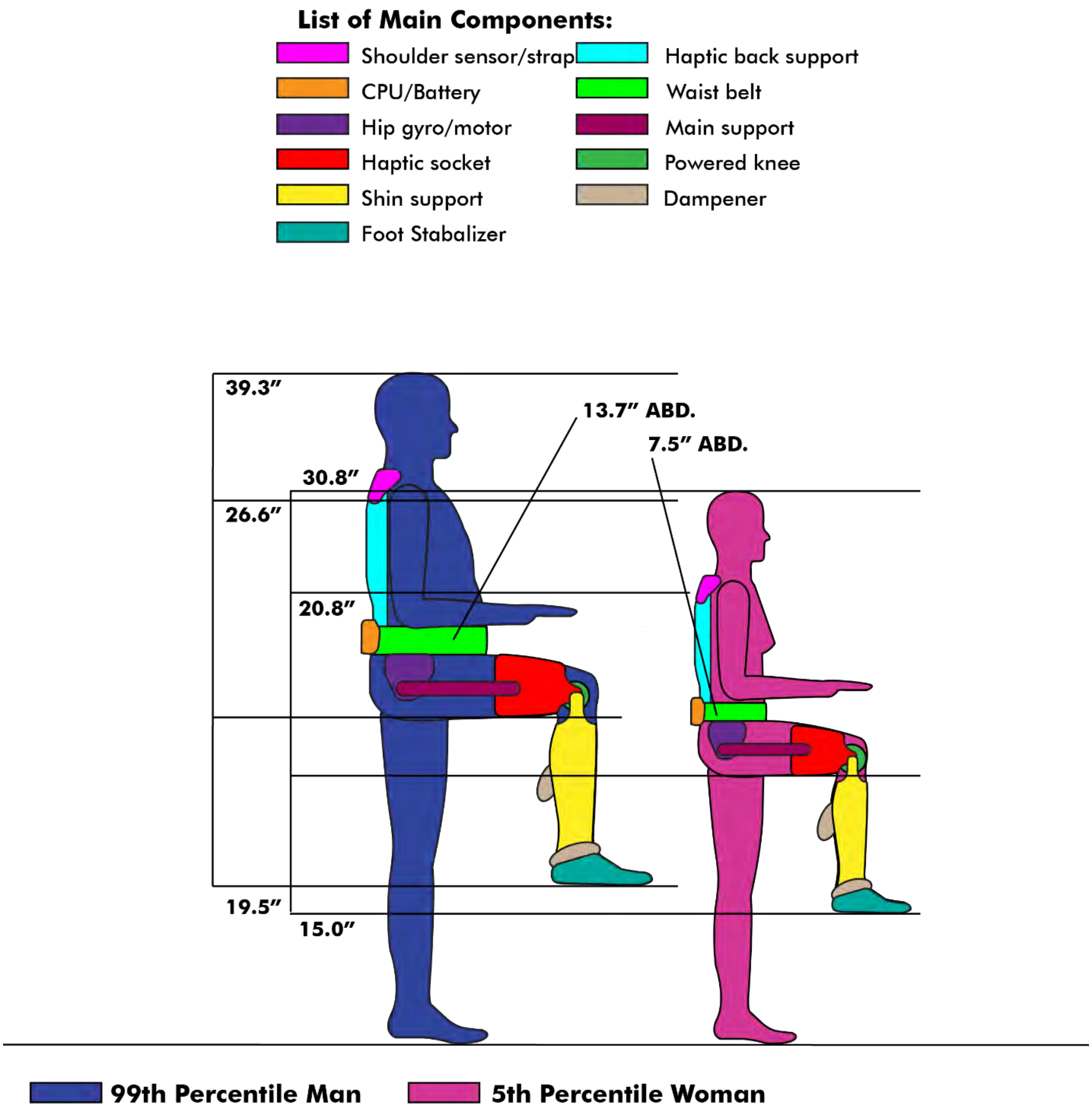


Figure 0-3: 99 percentile man & 5th percentile woman, with related dimensioning as seen related to potential mobility device.

Limitations and Conclusion

Observing users in motion found that users with lower-limb amputation have a greater need to lean with the upper body in order to gain momentum to move forward or backward. This indicates that users not only have users lost information from lower limbs, but lack control of current prostheses' which does not allow them for initiation of gait normally, and termination of gait is usually very forceful. Having the three major body section connected will in theory create and allow for more natural locomotion giving the user unimpeded gait.

Figure 0-4: 1:1 Ergonomic buck

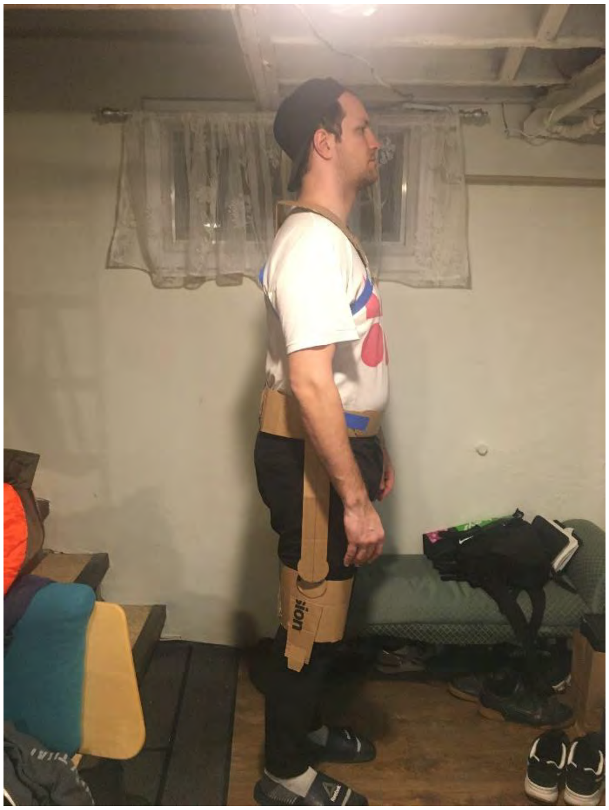


Figure 0-5: 1:1 Ergonomic buck

Figure 0-6: 1:1 Ergonomic buck

Figure 0-7: 1:1 Ergonomic buck

Figures 3-6 show the ergonomic buck while being worn. Key take a way include:

- Thigh socket must be adjustable and snug, adjustable strap on upper portion may aid in donning/doffing
- Thigh link should match opposing leg, potential for shock
- Thigh to hip link must be structurally supporting
- Belt needs to be snug and no impeding
- Power controller/cpu on lumbar sits more comfortably slightly lower
- Belt must adjust for many bodies
- Shoulder straps are inconvenience
- Potential for trunk belt
- Support to lumbar spine necessary, also aids with stretch reflex
- Minimizing bulk of the unit will aid in improved mobility/range of motion
- As is, very cumbersome
- Donning and doffing is not comfortable

Possibilities/Challenges

This study helped inform what challenges the proposed product will face and what needs it must meet ergonomically. The unit must find a way to marriage mobility, range of motion and structural support. Current iterations are cumbersome, there is a potential the unite the belt and back into a shorter version of itself, removing the cumbersome shoulder supports and creating a stronger shorter lumbar brace. The connection from hip to knee is also facing challenges as it must be reduced in size but the strength needs to remain a pertinent quality. These finding s will help improve and guide the final design direction.

3.4 Aesthetics

Introduction

A prosthesis or any other mobility aid is a very recognizable piece of equipment, due in part by the users need of the device during action of movement through space. Many devices have changed in appearance, but mostly due to the material construction or technological implements that are used in the devices. This section aims to, in conjunction with previous section, help decide design direction of the proposed product for this thesis project.

Objectives

- Compare existing designs
- Discuss design language of existing prostheses/exoskeletons
- Decide design direction
- Discuss semantics of proposed product

Method

This section uses section in chapter 2 to look into ergonomic, aesthetic, and semantic features of current prostheses and exoskeletons in order to create an understanding of the design language involved in their design. This discussion will aid in a design direction for the end result of this thesis project.

Results

Prosthetics and exoskeletons share features between themselves and between each specific product type, these features include but are not limited to components and ergonomic considerations. Some of these features include:

- User Weight Max
- Driving Force (motorized/battery)
- User Height Range
- Assistive Force
- Water Resistance
- Operating Time
- Links with User
- Materials
- Unit Weight

The semantics of prostheses are very strong as seen is sections of chapter 2 which researches into current benchmarked prosthetics/exoskeletons. Exoskeletons used for mobility typically have some form of waist belt, the belt is the main connecting point to the body as the center of gravity tends to sit around the navel. The belt is the housing for the battery and the CPU that controls all other functions. From the belt there is typically some form of back brace, most notably it is a vest with a sewn in support structure. Then from the belt leading down with the legs are the supporting structures for them. They connect at multiple points; the thighs, the shins, and the feet. And have motorized joints that coincide with the anatomy of user.

Prostheses are simpler but tend to have similar components. Typically starting at the socket, the most important feature. Then leading down to a knee joint controlled by a motor and a CPU housed in the main body that is shaped like a calve. This leads down with a supporting shaft to a shock absorber and a foot. Newer prostheses can mimic the look and texture of a real leg, while other opt to look very space age utilizing materials such as aluminum with some hard edges and lines.

Discussion

The final design direction will try to take elements of both. Taking hints from the exoskeletal support structure but hiding it away into a more concealable, natural package. While still retaining some newer design elements seen in prosthetics that try to emulate a space age or retro futuristic look. The over all design language will be that of the human body to maintain cohesive language, organic, beautiful and shapely. Though will implement rugged materials and some styling features noting that the final design direction will last the abuse of day to day use.

The semantics of the proposed mobility device will still retain some classic styling elements but will try to push further into a new or “futuristic” feel, bringing to life the feel of organic transhumanism by utilizing the implementation of exoskeletal frames into prosthetic use.

3.5 Sustainability – Safety, Health & Environment

Introduction

Due to the nature of their use, and the need for them to be reliable, mobility aids for amputees must maintain working order and be durable enough to withstand everyday use for upwards of 13 hours a day. The mobility of the user depends directly on the mobility aid, if it were to fail during use it could mean that the user sustains a fall/injury and could be left in a prolonged state of hindered mobility. The devices durability then hinges directly on the ability maintain working order. Currently mobility aids such as prostheses', walkers, canes/crutches utilize lightweight materials that are strong enough to support the weight of the user but afford strength and durability. The interactions and the spaces that the users will expose these devices to vary, from urban city centers to rural neighborhoods, and even natural environments such as national parks. The extended use of these devices, some being upwards of 13 hours, for a plethora of reasons; indicates that the materials must be selected to reflect their use, furthermore the health and safety of the user are the most important factor when considering the design features for the final mobility aid thesis proposal. By looking at current and future directions of sustainability related to health, user safety, and the environment; information can be gathered for the purpose of creating and deciding a feasible design direction and features for the mobility aid.

Literature Review

Reporting on sustainability for mobility aids in regards to lower-limb amputations requires an in depth look at sources on the topic of sustainability. This report looks at current and potential technologies being implemented in the field of mobility and balance for those with lower-limb amputations and mobility disfunctions. The article, *Review of nanocellulose for sustainable future materials,* discusses the manufacture and implementation of nanocellulose in the reinforcement of thermosetting plastics and medical sectors for hygiene and absorption products. Nanocellulose also has the unique quality of being able to successfully integrate with smart technology allowing it to synthesize with the proposed mobility aid in order to help create haptic feedback to the residual limb and spine during stretch reflex.

This report will also touch on the health and safety of the users. Reflecting on articles and reports found on this topic will help the discussion and analysis of these concerns. Two articles *Growth and Advancements in Neural Control of Limb* and *What Are Some of the Long-Term Physical Effects of Using or Not Using a Prosthesis.* These articles give an overview of the negative long- and short-term health effects of living with a lower limb amputation and the possibility of and possible effects of introducing neural control to prosthetics. The introduction of some form of neural control has the potential to not only alleviate some of the negative health concerns, but also reintroduce the haptic information that has been lost due to amputation including stretch reflex and the subtle balance controls in the ankle, knee, and hips. Another article to supplement the effects of balance control, health and limb loss was used, the article named *Human balance and posture control during standing and walking* helped develop an understanding of the users' needs and potential effects of loss of balance control. These articles were used to help enhance the understanding of the topic and provide evidence for their need in order to help provide a clearer final design solution (US6537589B1).

Sustainability

Many companies who manufacture prostheses and other mobility aids utilize aluminum because of its strength to weight ratio, and composite materials such as carbon fiber for the same reason. The problem that needs a solution is that some components are unable to be mass produced. So, a material that is sustainable and still able to be utilized in the same manor needs to be introduced. Carbon fiber is non-recyclable and aluminum is only partially recyclable.

Nanocellulose (nano structured cellulose) a wood-based pulp fiber extracted from plants is used to reinforce plastics, and is reported to improve the mechanical properties of thermosetting plastics such as PLA (polylactic acid), and are more recently being introduced into elastomers and polycarbonates creating a more sustainable yet durable and mechanically sounds finished product. These bioplastics are also reported to be used in the design and manufacture of transparent haptic relays which will play a major role in the final design (Kim, 2015).

Additionally, research was conducted into the use of materials such as artificial bone as a substitute to aluminum and or any of the other supporting structures of the brace. The calcium phosphate artificial bone, which is osteoconductive and osteoinductive; is a strong, biodegradable material, that under the right circumstances and research could potentially be a self-healing material with some external stimulation. The material is also on par with aluminum for strength to weight ratio and is currently being used to help restore bone degradation as a paste, and 3D printed as implants for patients with severe trauma/bone loss.

Health

Immediately after the procedure of amputation, the health of amputees becomes an issue, not to say the health of someone who is expecting amputation surgery isn't important. The reason for the increased health risk is not only due to the recovery from surgery; limb loss, bone deterioration, blood loss, scarring, etc.; rather health is mostly affected by what is happening post-surgery. Despite the high-tech solutions to amputation, prosthetics users eventually find physical effects related to the method of suspending the prosthesis on the residual limb.

The environment within a prosthesis liner has the potential to be a hub for bacteria causing; increases skin temperature, sweating, heat rash, blisters, contact dermatitis, abrasions, and even ingrown hair. These skin issues can progress to very dangerous conditions and infections.

Furthermore, using a lower-limb prosthesis can lead to issues concerning postural alignment, muscle imbalances and strains, and gait abnormalities. The incidence of back pain among lower-limb amputees ranges around 80%. The residual limb is susceptible to deep tissue injuries from forces due to prosthesis use. Intact limbs of lower-limb amputees are much more likely to develop joint and bone problems such as arthritis as amputees habitually load the intact leg more (LaRaia, 2010). Additionally, the body during moments of quite stance must be allowed the freedom of motion in order to achieve maximum balance efficiency. Without the haptic response/information from one or even both legs, balance and locomotion become a difficult task. Virtually all neuromusculoskeletal disorders result in some degeneration in the balance control system (Winter, 1995).

Safety

The locomotion of the human body is an active, dynamic event in which the body is constantly subconsciously adjusting to the environment and how it is overcoming obstacles, elevation change, and change in direction. As a result of the dynamic nature of mobility specific pivot points associated with mobility must accessible to the user and allow for freedom of motion while offering support to the musculoskeletal system (Winter, 1995).

Living with lower limb amputation places users at greater risks of falling. Minimizing risks means the awareness of many factors, some of which include; reducing travel over uneven or loose surfaces such as rugs or gravel, observing the path of travel watching for hazards, staying mindful of inclines/declines, cluttered spaces, adequate lighting and the use of grab bars. Even tasks that seem simple or mundane such as bathing or using restroom facilities can be extremely dangerous for even the most able-bodied amputees without the aid of grab bars or some form of support (Cristian, 2006).

Final Design

The aim of the proposed product is to enhance the mobility of amputees by restoring some elements of haptic response and stretch reflex, while contributing to the support of body post lower-limb amputation and allowing the offering enhanced mobility through the combination of ergonomic factors associated with the support structure and full-body human interaction. The final design will incorporate sustainable aspects for user health, safety, and environment.

In regards to health the final design will have a redesigned socket that will utilize nanocellulose, being that it is breathable, antimicrobial, and has the ability to be soft/flexible and rigid/strong. The main supporting structure will also aim to reduce forces on the residual limb by having open bottom style socket that redistributes the forces from locomotion to the hip and spine creating a more natural gait. The prostheses will also include shock absorbers to dampen the impact of walking located at the knee and ankle.

Safety will be addressed by improving balance by incorporating neural transmitters in the socket liner and the spine pack. The transmitters will be constantly feeding information to the user about the position and forces on the prostheses. Furthermore, the ankle will be sending and receiving information about the users position and posture because of the neural transmitters helping them with balance during quite stance and locomotion.

Lastly, environmental concerns will be addressed by utilizing nanocellulose. Its ability to be implemented in a majority of the parts as a stand-alone flexible foam or a reinforcing material for thermosetting plastics means a lessened impact on plastic waste as nanocellulose is derived from plant fibers and is biodegradable. Aluminum will still have to be utilized as the main structural supporting system.

Conclusion

In conclusion, new materials and manufacturing methods are improving the prostheses industry, though some of the parts have to be custom made for the individual user. As improvements and innovation move forward, far better materials will be made available at lower costs monetarily and environmentally creating a more sustainable industry in mobility aids.

3.6 Commercial Viability

To understand commercial viability of the proposed concept, please refer to the bill of materials in Appendix IV.

3.6.1 Materials and Manufacturing Selection

To understand commercial selection, manufacture and viability of the proposed concept, please refer to the bill of materials in Appendix IV.

Materials

Currently prosthetics are taking advantage of strong lightweight materials such as aluminum, connected to a carbon fiber socket mold containing a silicone socket liner. Since the very first-time mobility came into question due to amputation, the goal has remained the same, but now the methods in which people are fulfilling those goals is changing. Materials and computers are becoming more advanced allowing manufactured to push the limits of what their devices can do. The introduction of CPU controlled gait has dynamically changed the possibility for the end outcome of what a mobility device can be and how they are operated or respond to the human body. Doctors are now experimenting with limbs that are controlled externally with neuro connections, allowing the device the understand the signals the brain is making and respond to the accordingly, thus changing the landscape of current materials used (Rajak, 2015).

Manufacturing

The manufacturing process for prostheses is much like any product, where standardized components are made in bulk in a factory, then sent out to the manufacturer's distributors. The key difference with prosthetics is that each device is made to order and completely custom. When the parts reach the end user, they have been assembled to fit him/her in the best possible way. Furthermore, the connection point, the socket, is completely custom. Without a custom construction for the socket the user would have difficulty moving or feel burdened and clunky.

3.6.2 Cost

The cost of powered exoskeletal devices can very, and is still in the process of development due to how new the application of this technology is. The estimated cost of a device like the proposed thesis product could be anywhere between $40,000 to $100,00, the range between high- and low-end exoskeletons makes it difficult to precisely estimate.

Table 3.6.2.1

Type	Cost	Notes
Indego	$80,000	
Ekso	$100,000+	clinics only
Hal 5	$20,000	qualifying patients only
Honda Walking Assist	$375 monthly	bulk sale only - supports upper legs only
SuitX Phoenix	$40,000	test pilots only
ReWalk	$77,000	

After analyzing the current costs of similar products, the final mobility aid should take advantage of easily produced components in order to cut costs to manufacturing. In order to fully understand and or estimate the potential cost for this product each component/assembly should be individually priced.

3.7 Design Brief

Introduction

The goal of this design thesis is to design a mobility aid/device that will provide improved mobility for lower-limb amputees, this mobility aid will consider ergonomics, comfort, safety, and ease of use.

Objectives

Objectives to demonstrate the needs addressed as follows:

- Improve the overall mobility/gait of the user
- Provide natural feel when walking
- Assist user so less energy is exerted during movement
- Improve stability and balance of the user
- Implement neuro/cerebral devices that track user's movement
- Improve safety of user
- Follow semantic design of exoskeletons and prosthetics
- Develop a socketing system that is less strenuous on the user's residual limb
- Develop a system that is modular and or easier to use, including donning and doffing of articles attached to body.
- Use human-centered design thinking to develop the product

Conclusion

This chapter covers the needs demanded by the user and product alike. Good design keeps the user in mind during the entire process, it allows the user to be the inspiration for the design, allowing it to grown and evolve into a product that the user needs and wants. The needs of the user have driven past design and will continue to push innovation as this project and others move forward.

CHAPTER 4: Design Development

4.1 Ideation

Introduction

Starting the design process involves generating ideas by putting pen to paper in order to iterate as much as possible. Sketching out ideas allows me as an industrial designer to create as many possible form factors as possible, very quickly. And in exploring all of those forms I'm able to flush out which design direction I think are strong, unique, and more aesthetically appealing.

Objectives

1. To begin the design process
2. Brainstorm and generate ideas
3. Create an understanding of what features to incorporate, which ones are necessary.
4. To generate as many form factors as possible
5. Decide on a concept direction for further development.

Results

The following are sketched done for the ideation phase. These concepts were drawn during an in-class sketching periods, where the task was to initiate the design process by sketching potential directions for the final design direction. These were the sketches the influenced the final design direction.

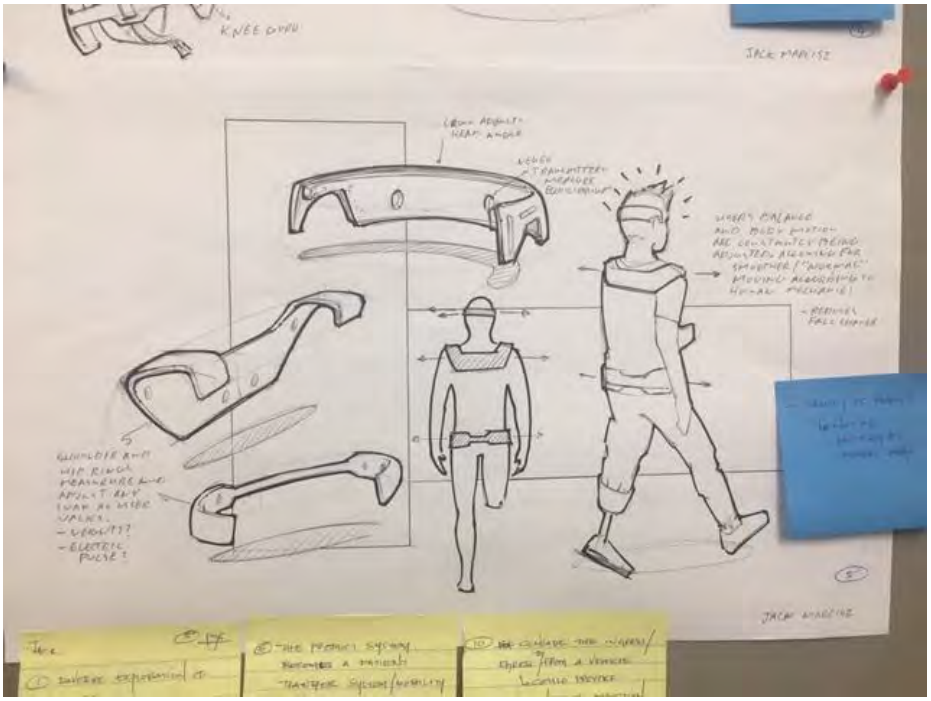


Figure 4.1.1

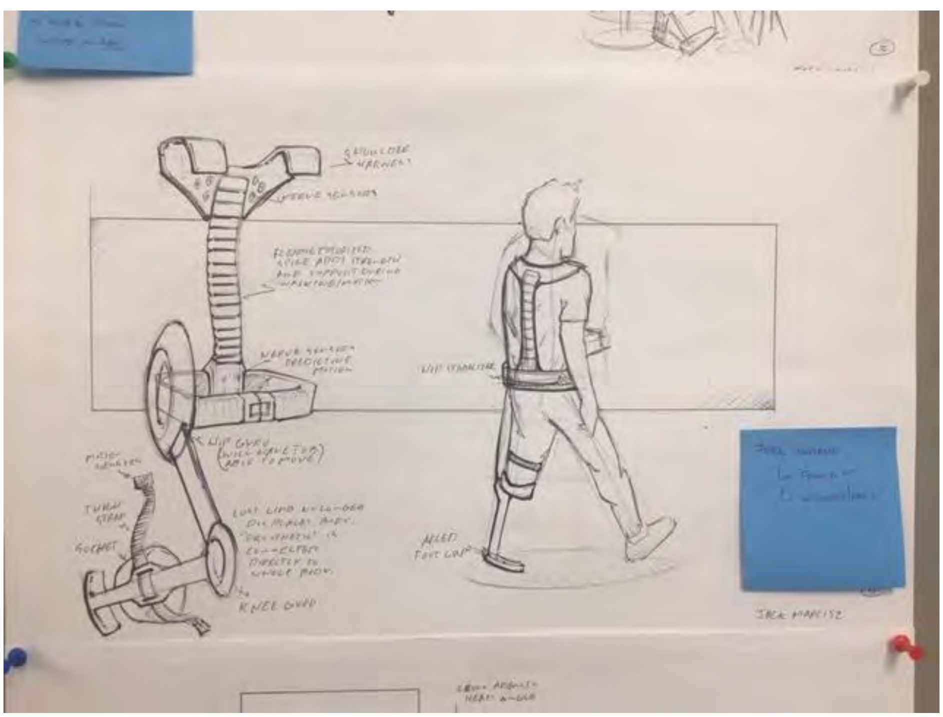
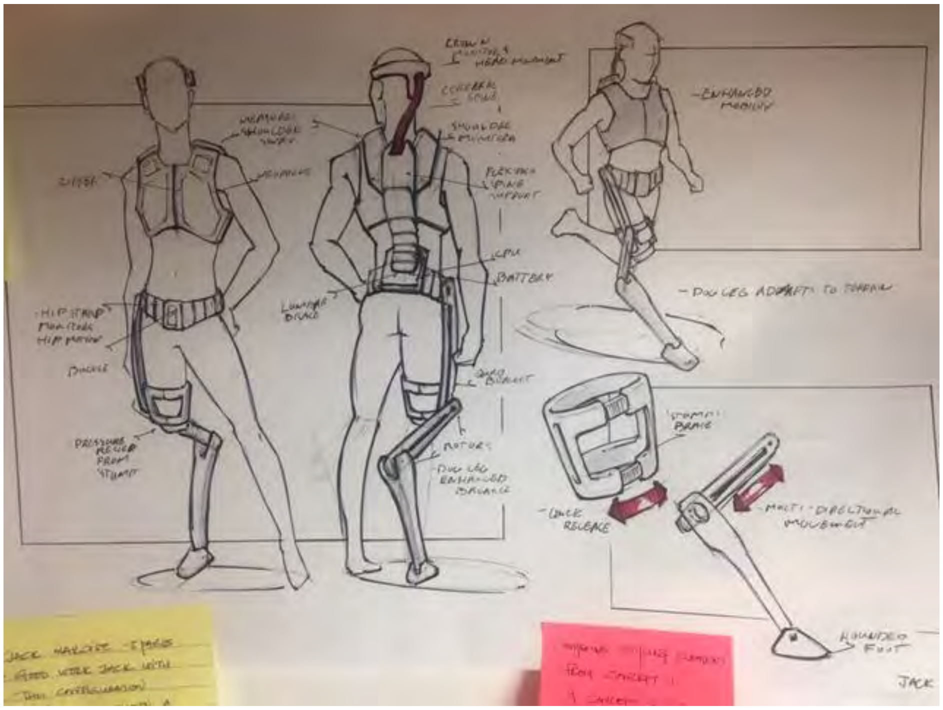


Figure 4.1.2



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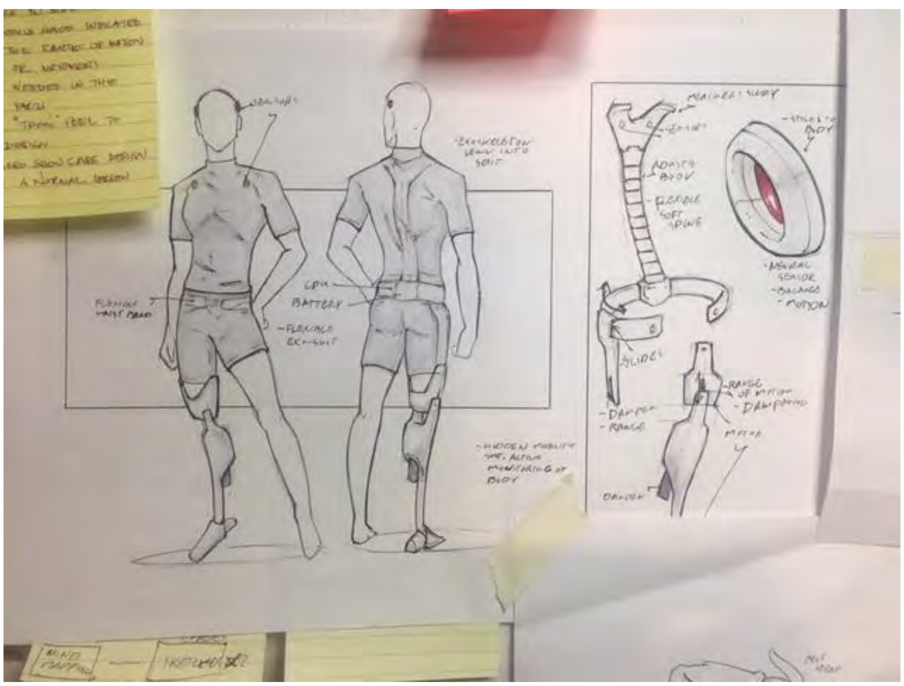


Figure 4.1.4

4.2 preliminary concept exploration

Introduction

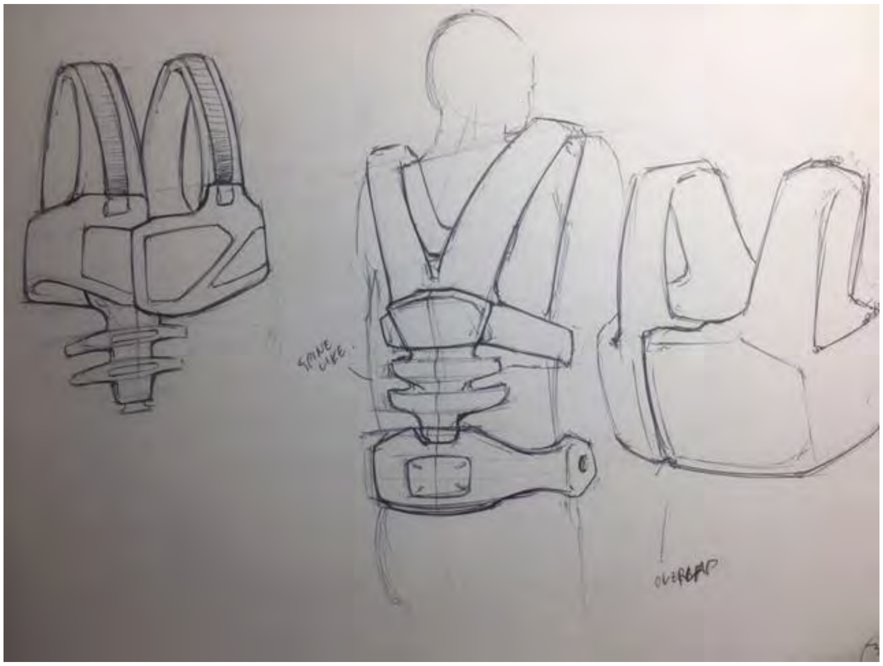
After the initial ideation stage of the design process, comes the concept development process. During this stage, the strongest concepts from the previous stage are expanded on and further developed into more feasible directions; this involves flushing out some details and features as well as strong and weak designs.

Objectives

1. To take concepts from the ideation stage further
2. To explore design direction
3. To understand prosthetic and exoskeleton semantics
4. To decide on concept direction

Results

The direction from the ideation stage chosen was a prosthetic mobility device that is integrated into an exoskeleton or balancing system. The following sketches were further developed in many directions in my sketchbook in order to flush out all the possibilities. The stage involves lots of iteration and form exploration.



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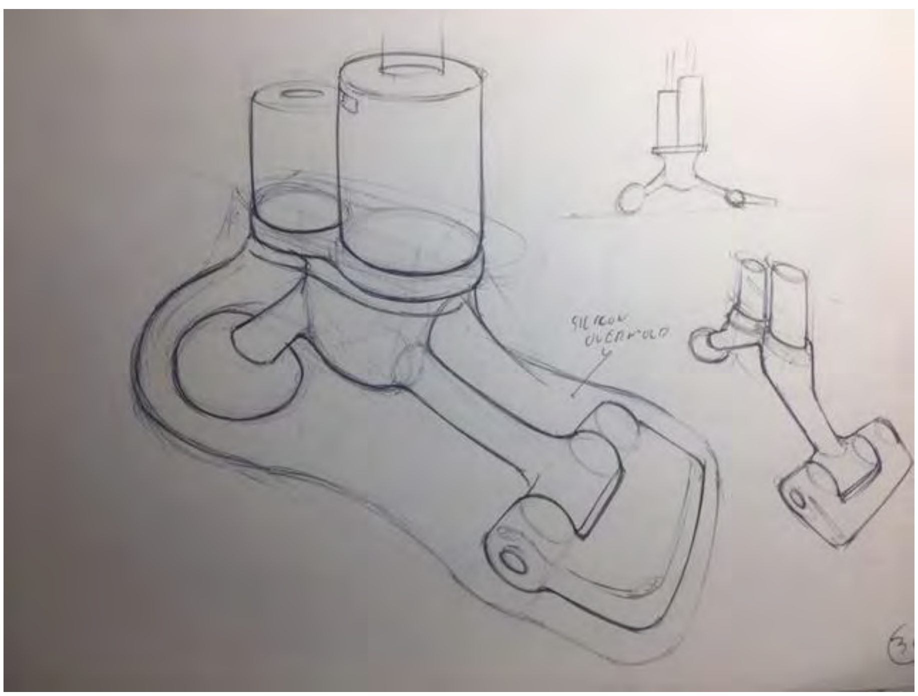

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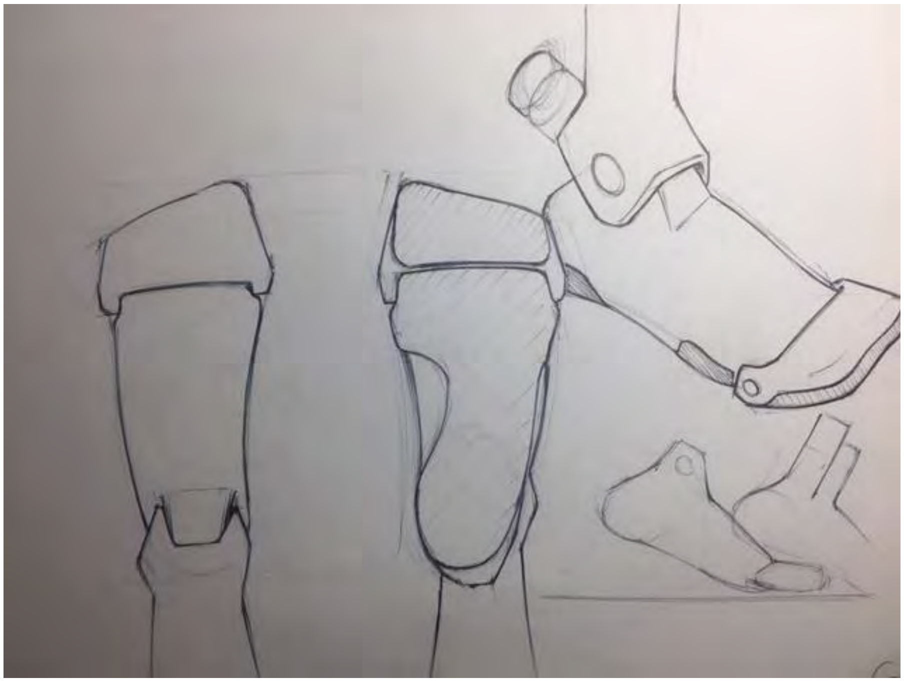

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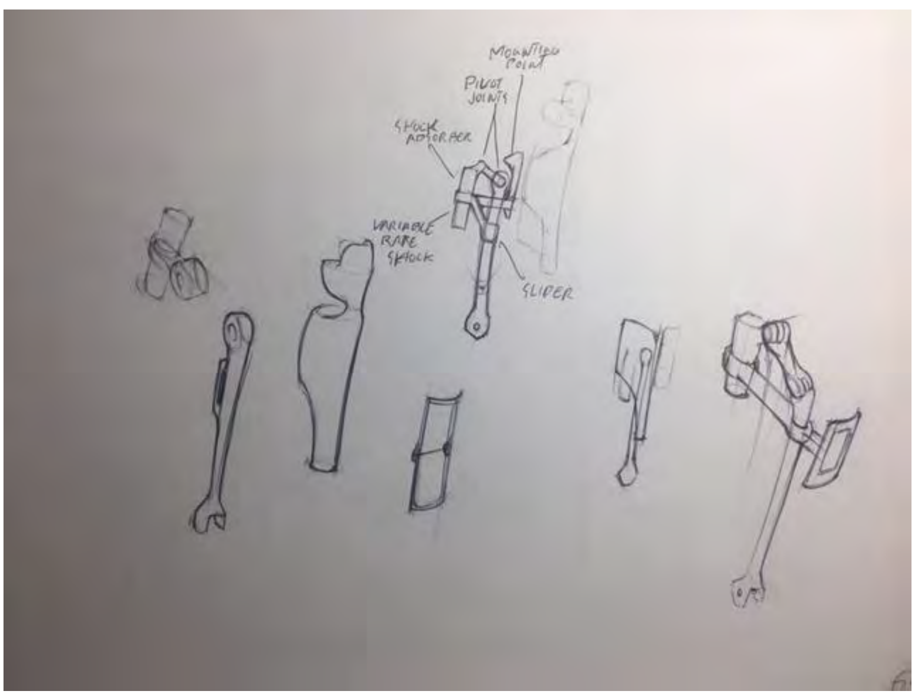

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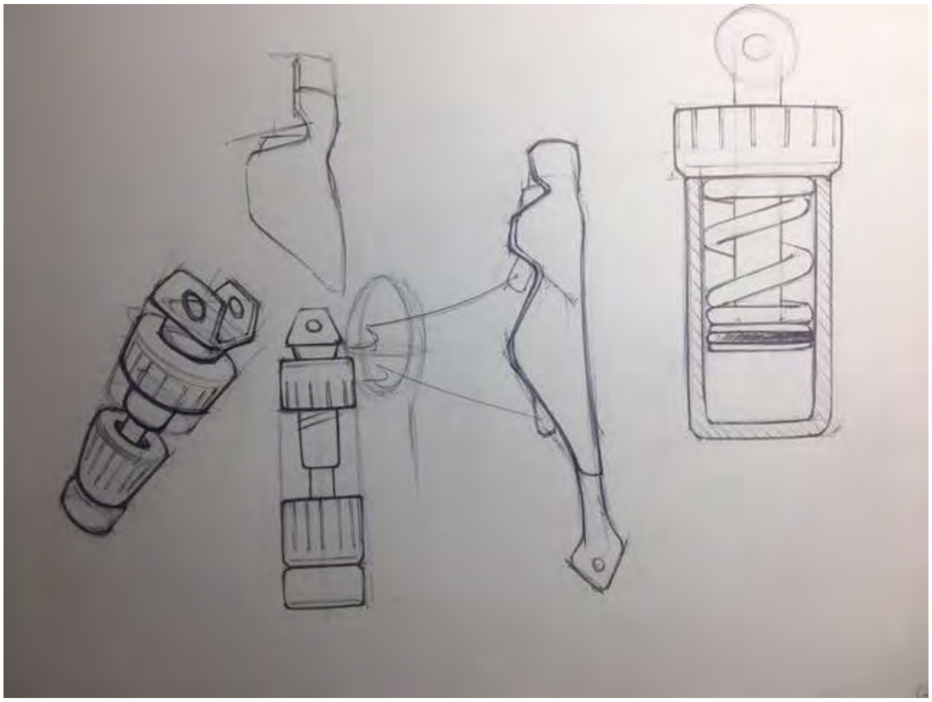

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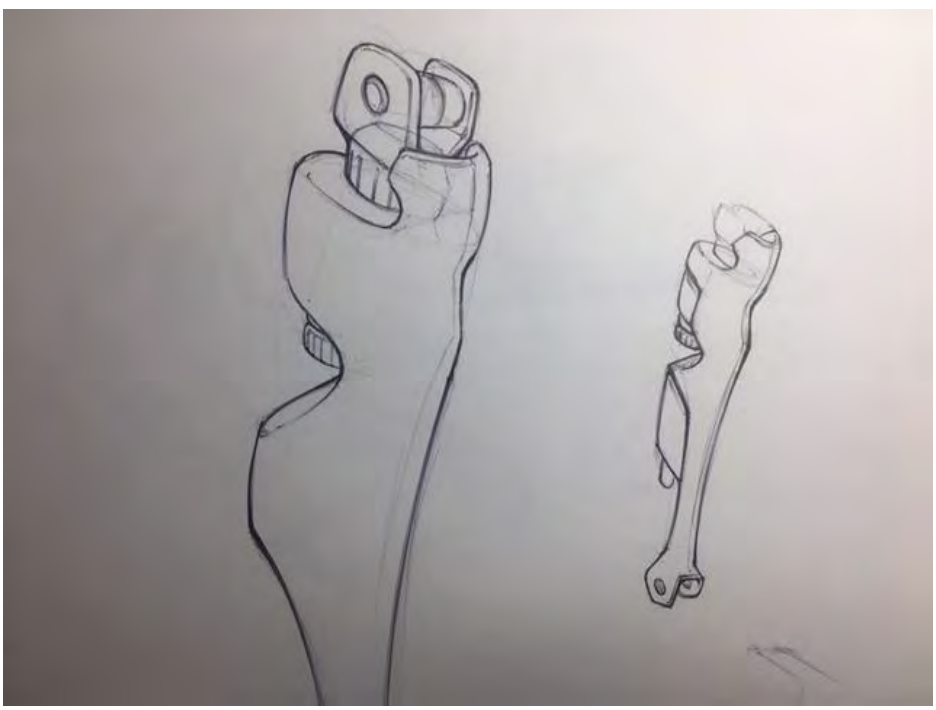

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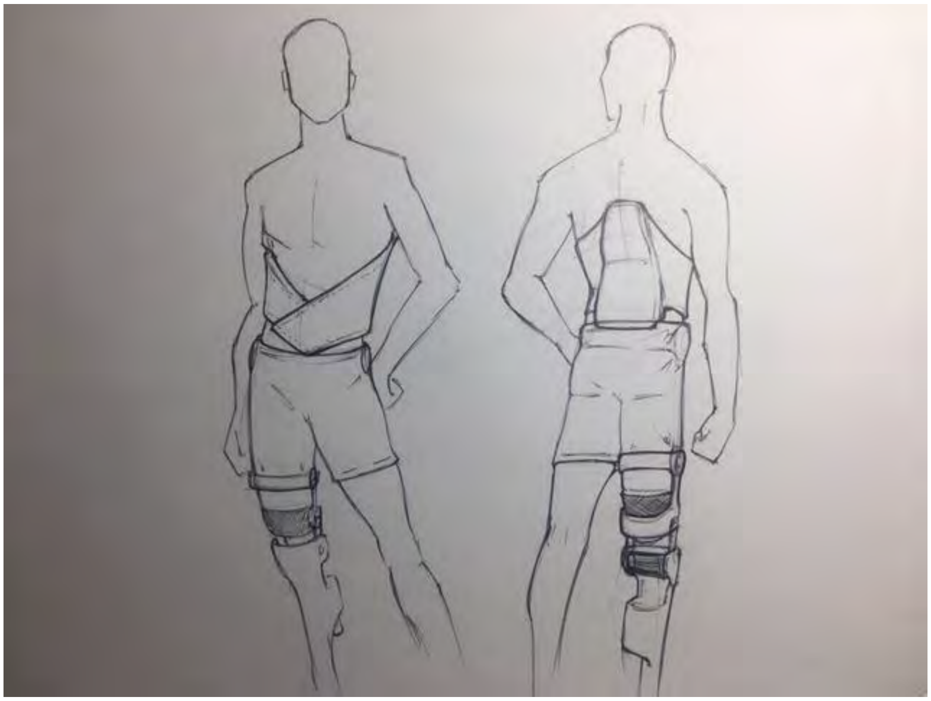

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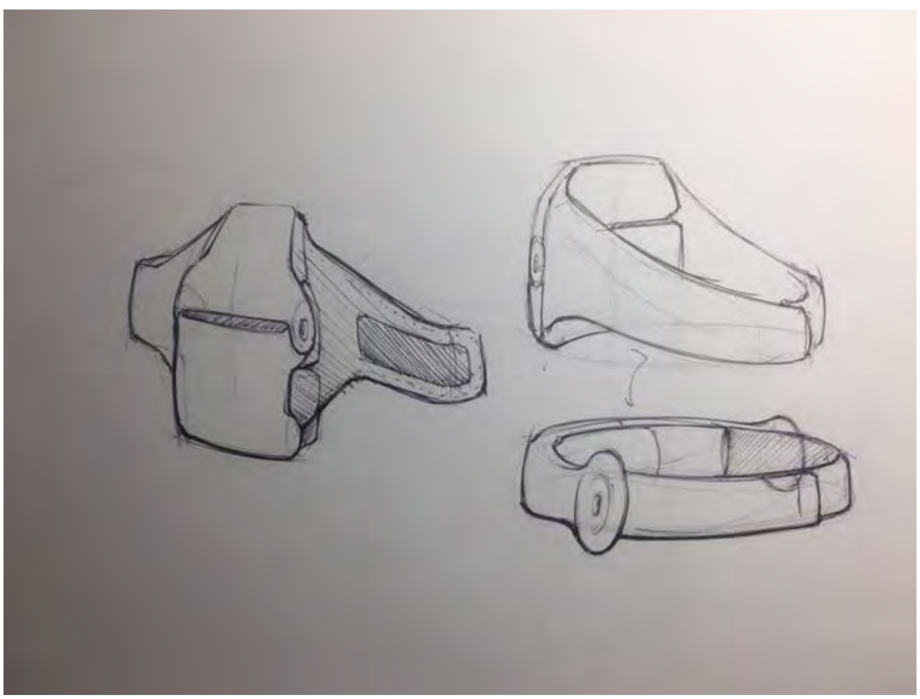

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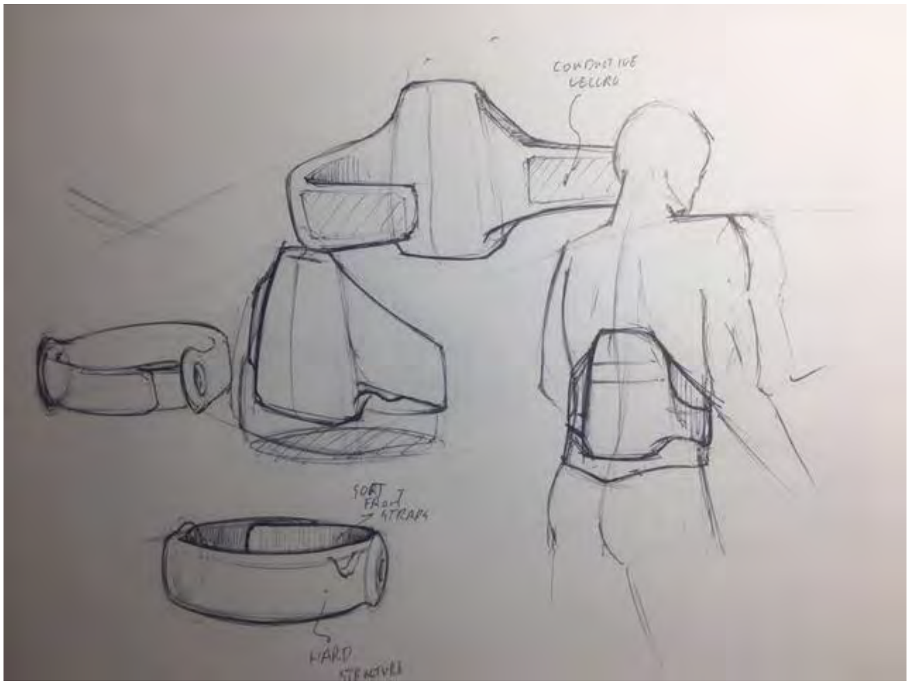

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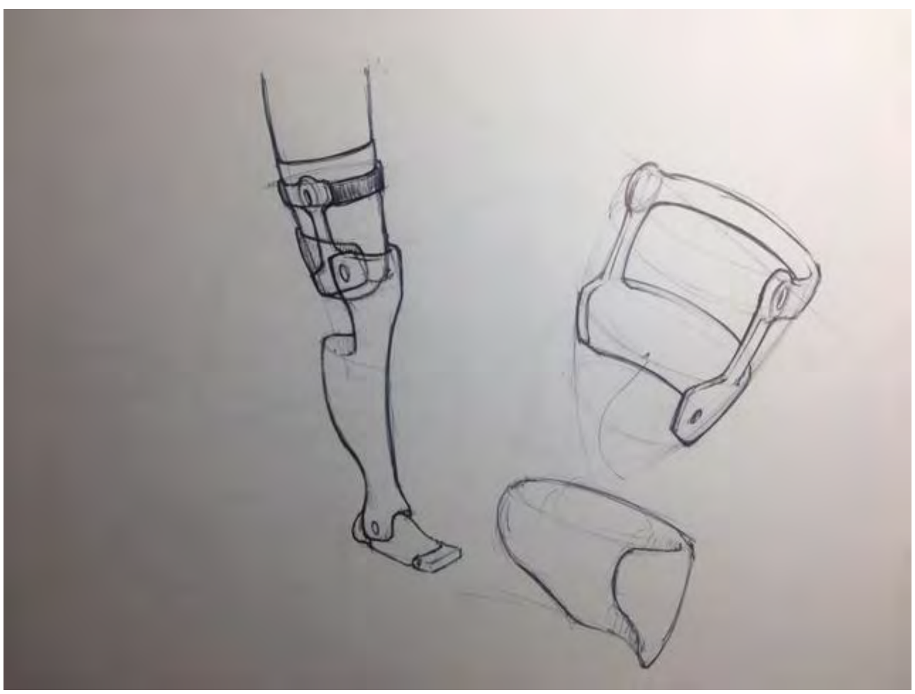

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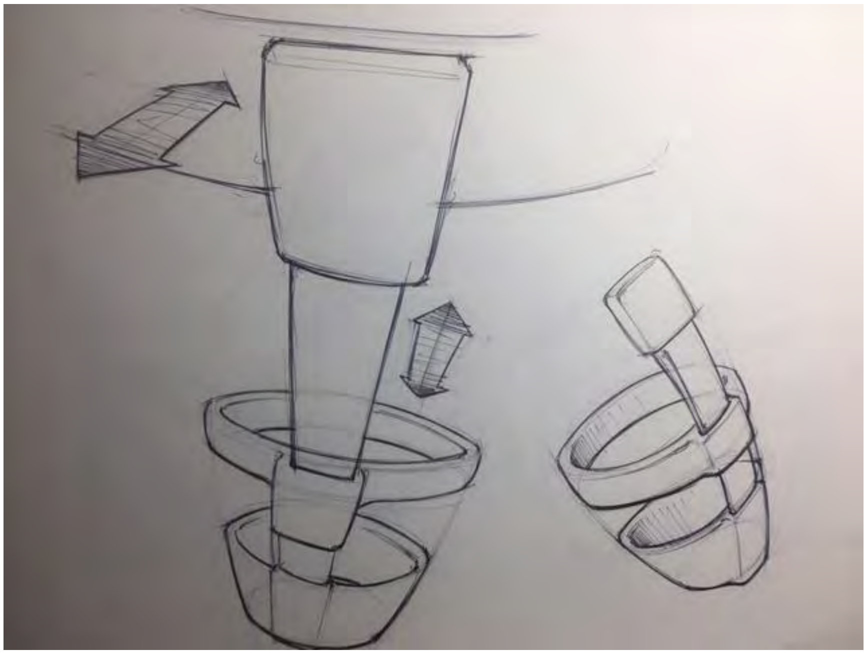

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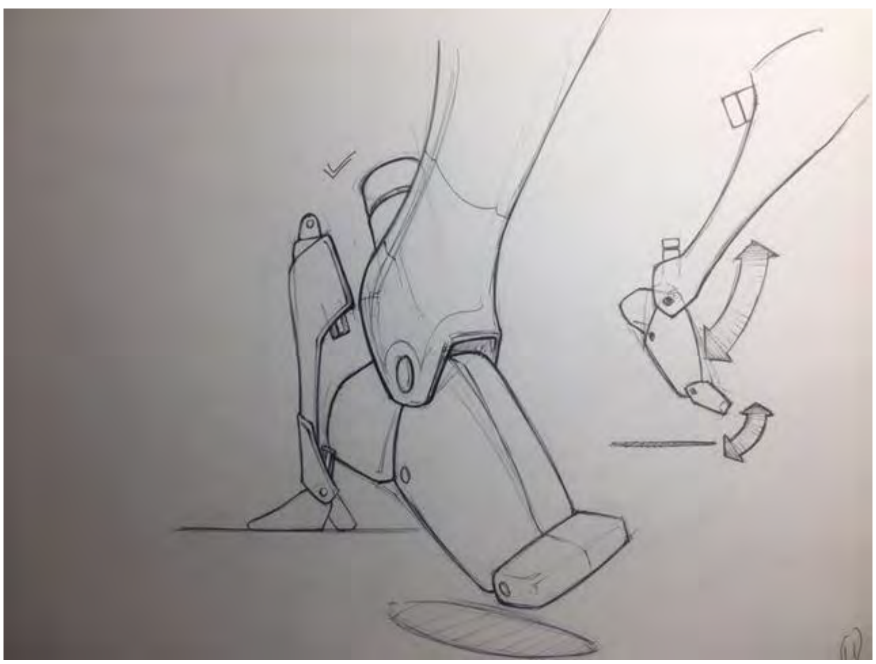

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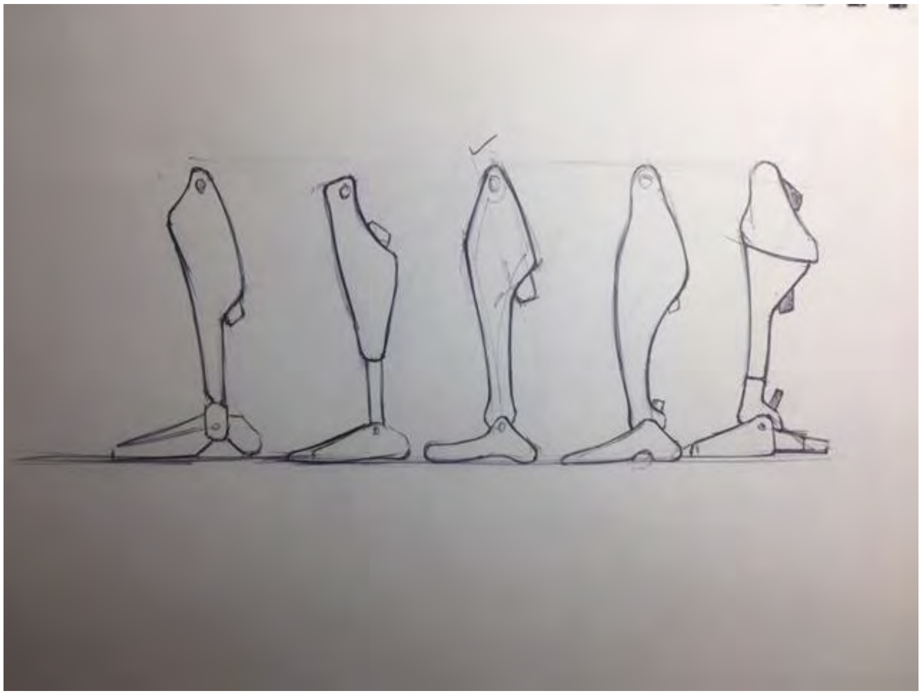


Figure 4.2.13

Figure 4.2.14

Figure 4.2.15

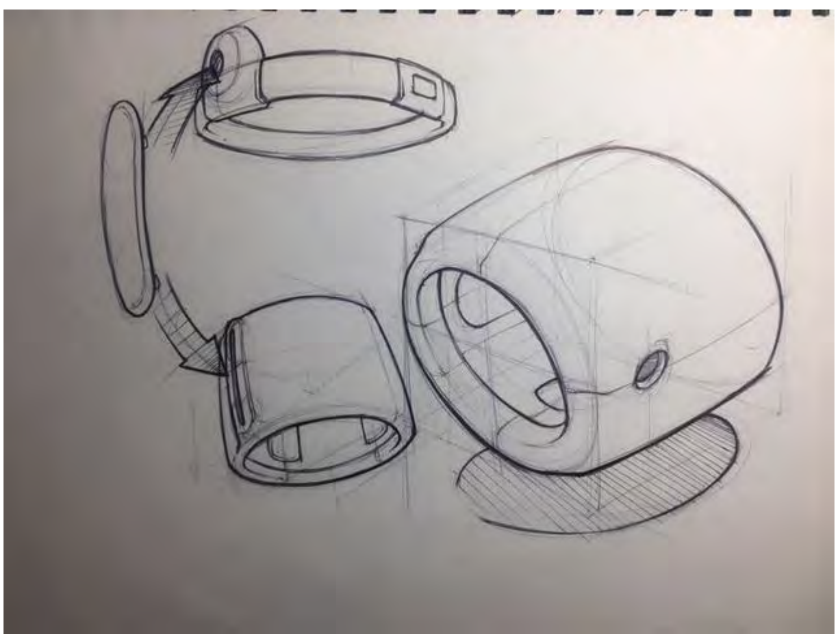


Figure 4.2.16

4.3 Concept Refinement

Introduction

During this phase, the final design direction is flushed out, every little detail needs to be considered. This concept will be the final design direction for the final product. This phase included sketching and some brainstorming in order to develop the final concept.

Objectives

1. To refine previous concepts
2. To design form, features, and functions.
3. To incorporate sustainability into the concept
4. To identify final direction.

Results

The following concept sketches are the result of an in-class exercise where we sketched our final refined direction for the concept. This exercise cemented the final direction the product would take as well as finalize details and features the final design would need. This step was the culmination of understanding the design semantics of the final product.

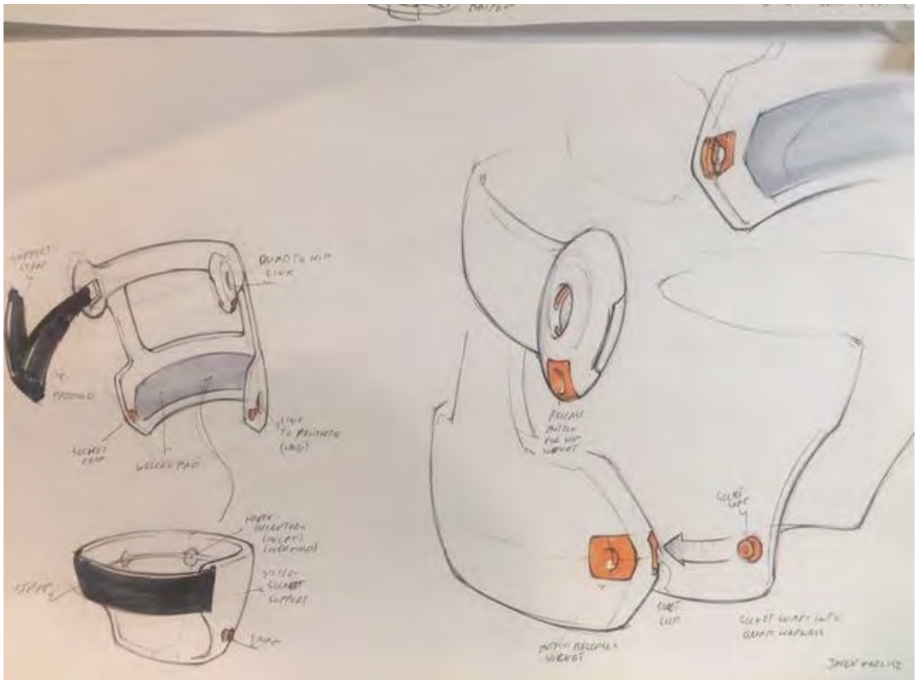


Figure 4.3.1

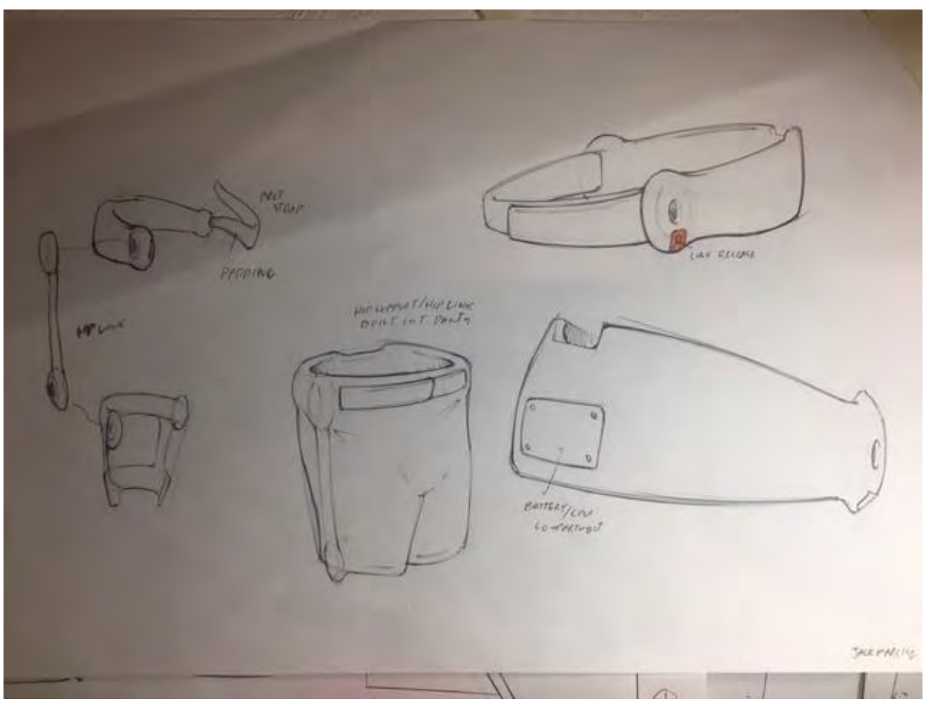


Figure 4.3.2

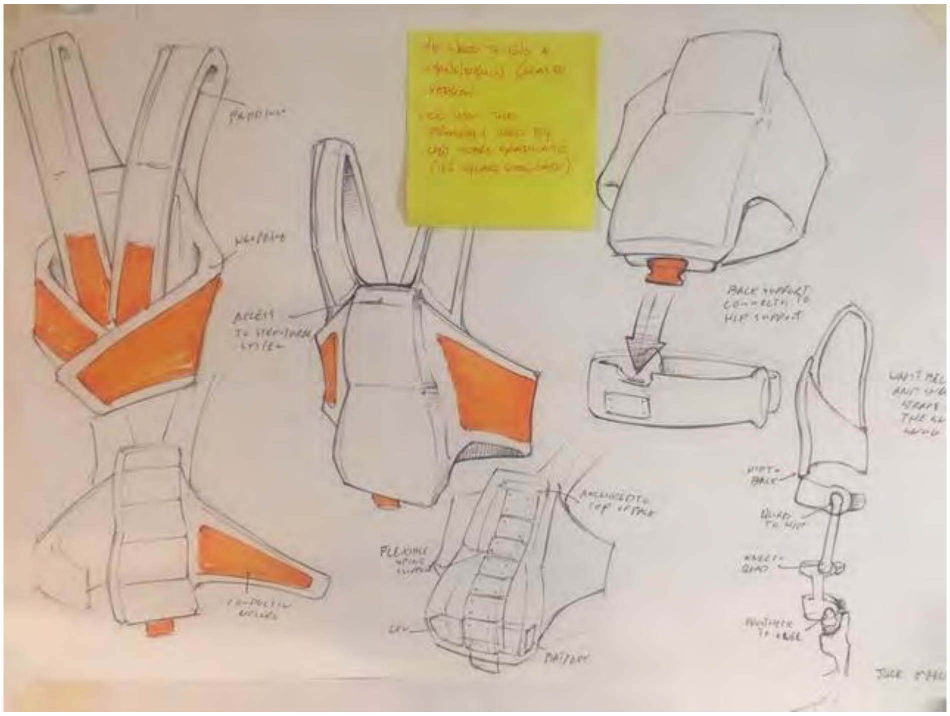


Figure 4.3.3

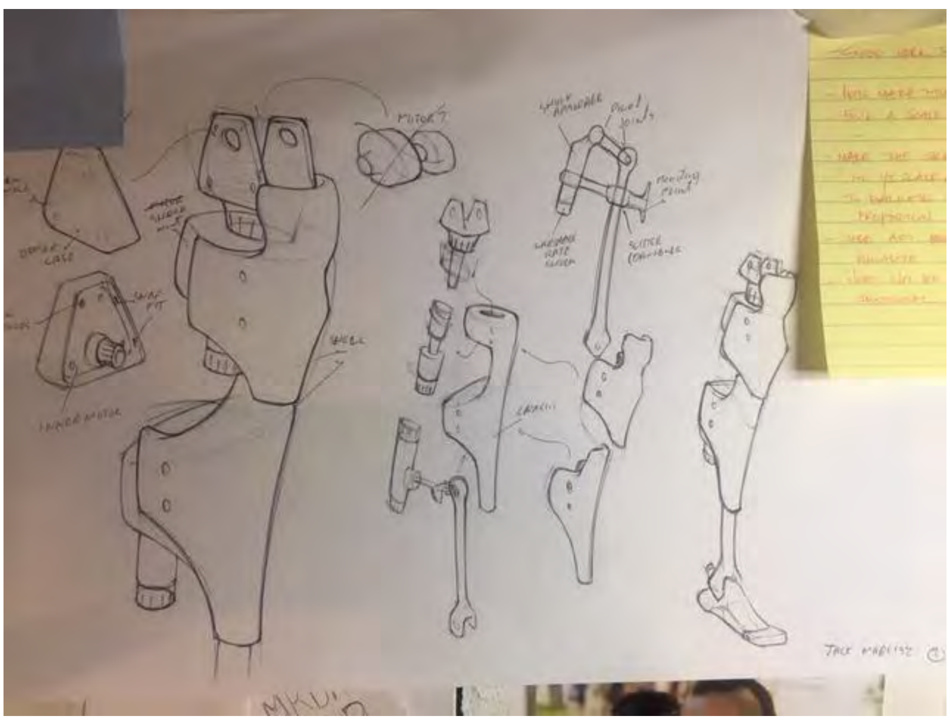


Figure 4.3.4

4.4 Sketch Model

Introduction

Creating a sketch model of the final design is an important step to understand the final dimensions and how the product will look in scale. In some cases, the product looks great on paper, but doesn't have the same appeal when transferred to a real physical model where it has to apply to human ergonomics. The sketch model was made to create a deeper understanding of the complete form factor of the final design direction.

Objective

1. To create a scale mock up of the final design
2. To understand the final form factor
3. To figure out the scale of the final model

Results

The sketch model was made using crude materials allowing me to create it rapidly while still maintaining a level of fidelity that would enhance the understanding of the final model. This model was made in the same scale as the final model and included as many details as possible.

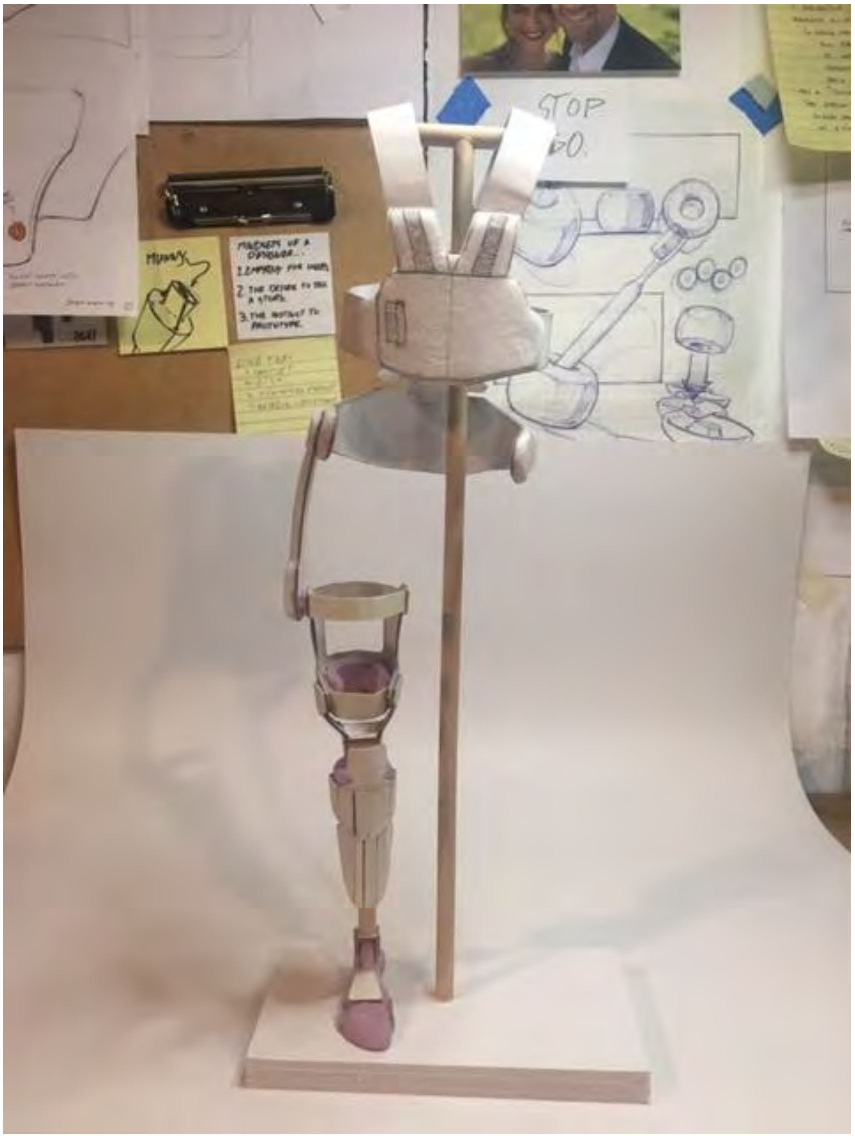


Figure 4.4.1

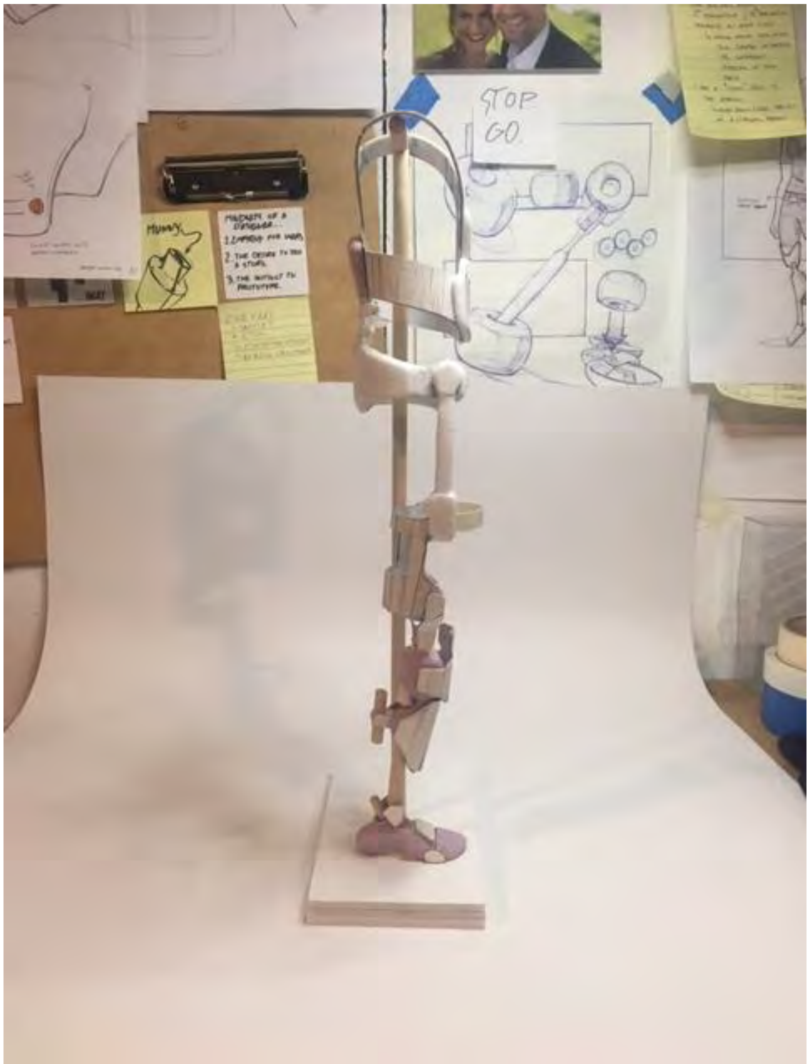
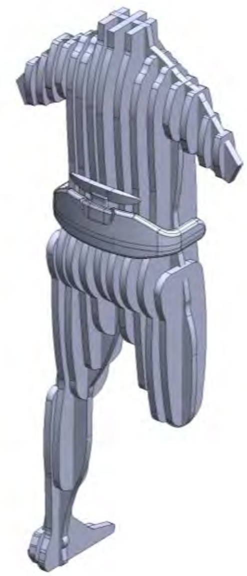


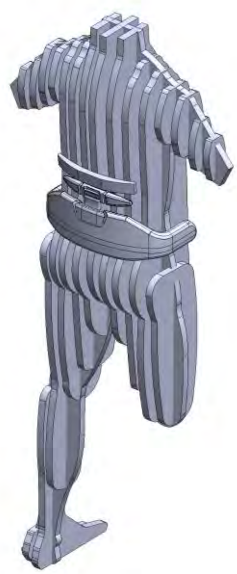
Figure 4.4.2

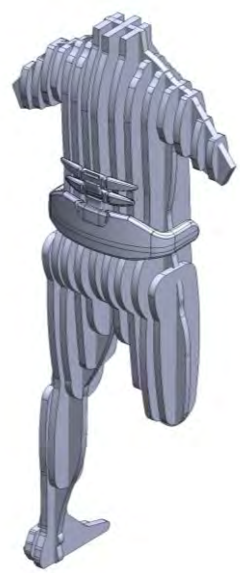
Figure 4.4.3

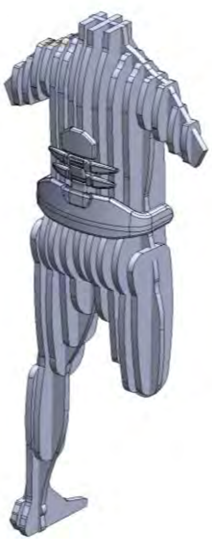
Figure 4.4.4

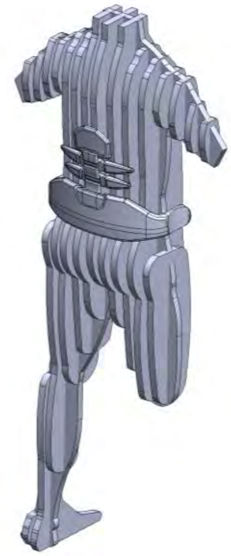
4.5 CAD Process

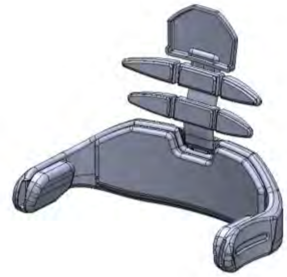


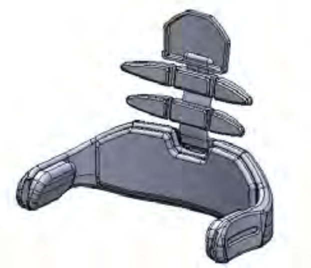


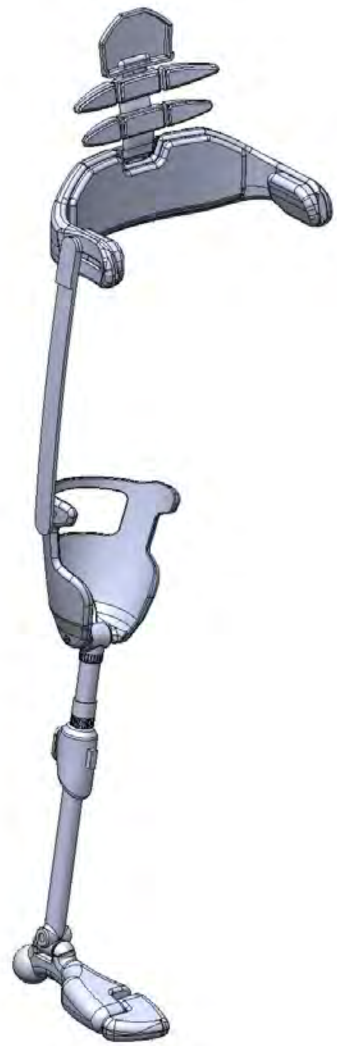


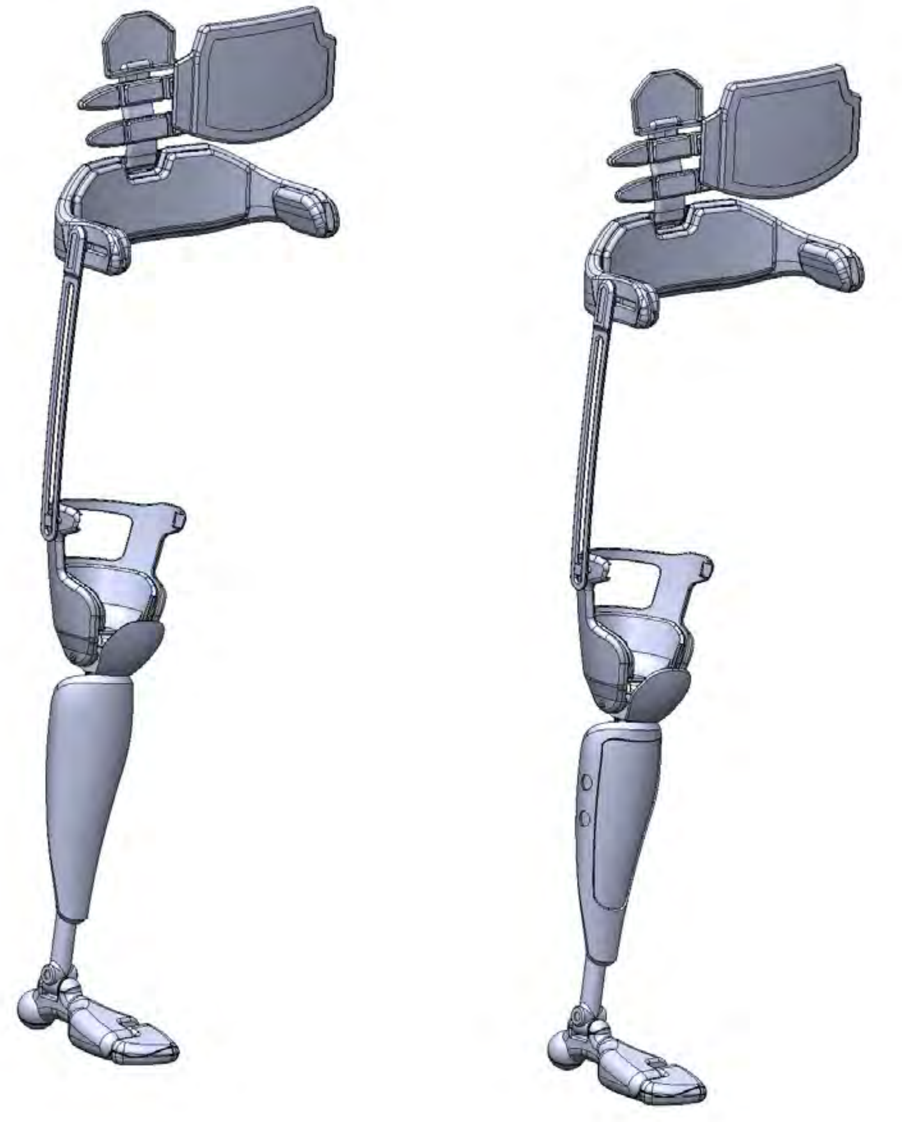


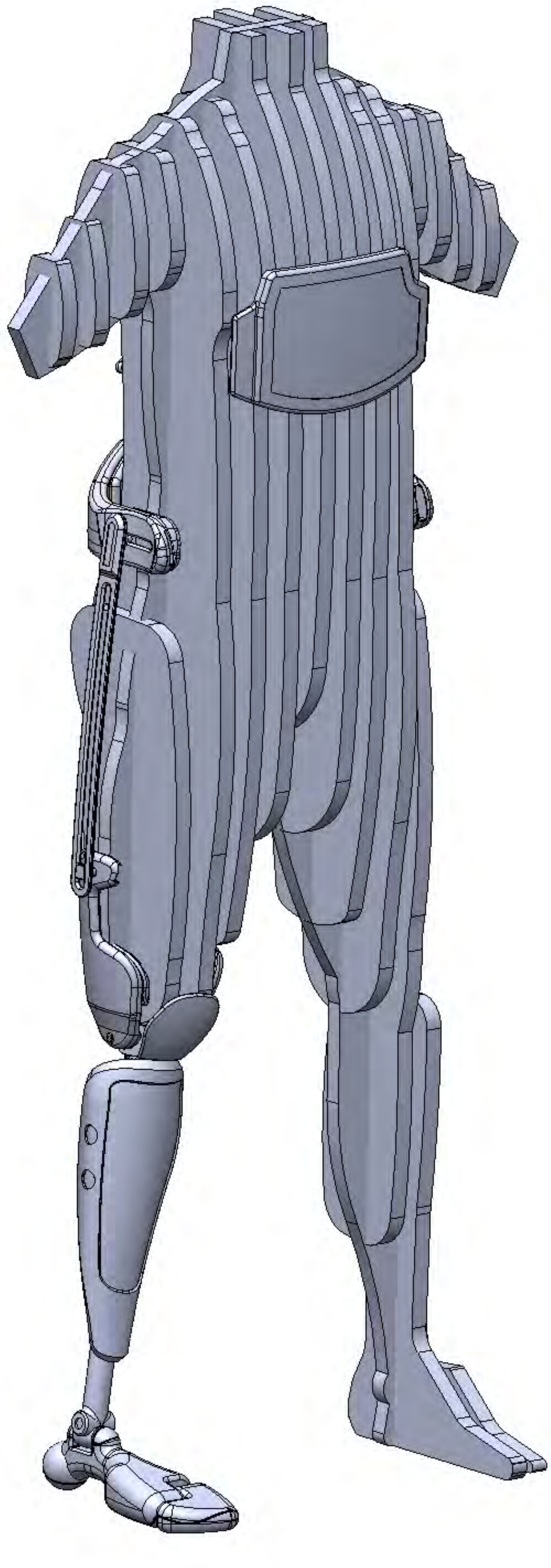




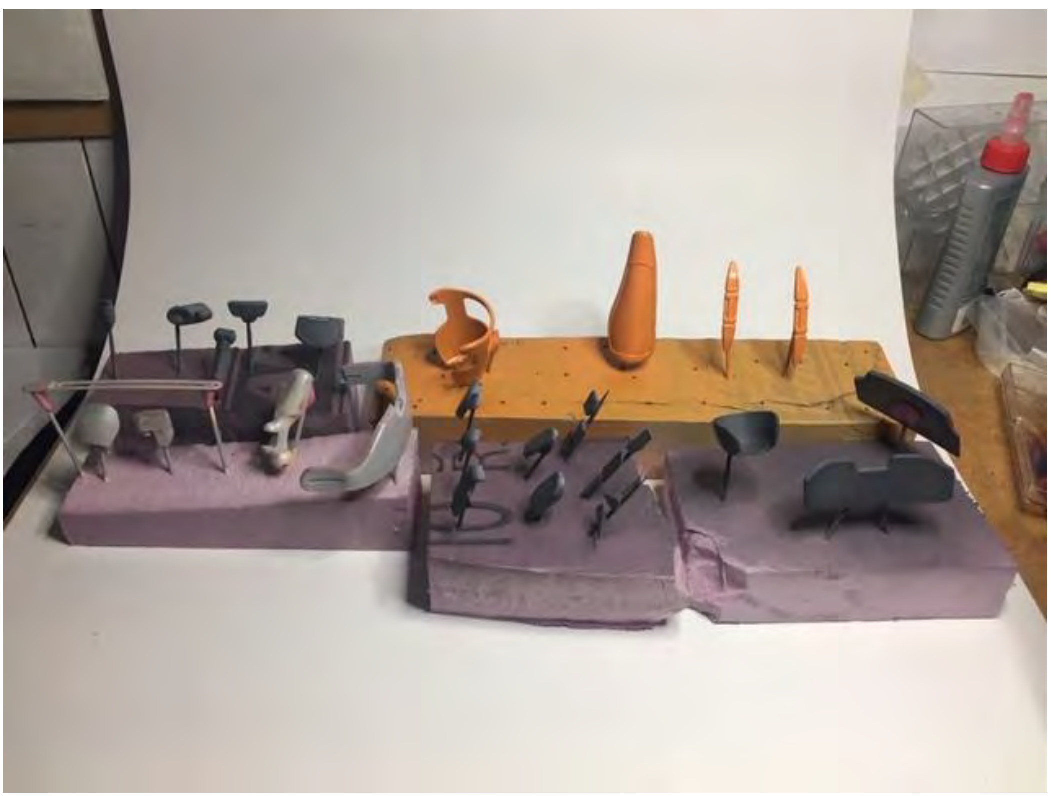









4.6 Hard Model Fabrication




STOP
GO.
KOI NO YOKAN

CHAPTER 5: Final Design

5.1 Summary

Description

Pacer is a prosthesis exoskeleton, mobility aid, for people with lower limb amputations. That was designed using the techniques of human centered design to improve ergonomic working conditions, health, and overall lifestyle of the users.

Explanation

The rates at which amputations occur are on an incline, not simply due to trauma but also because of health complications. People who suffer and amputation, regardless of the cause, face a very difficult life ahead; and without proper rehabilitation and equipment to aid them, namely in mobility. Their lives tend to become that much more difficult forcing amputees to drastically change how they live their lives and cope to their new situation. Furthermore, mobility aids such as prosthetics, are not advanced enough to offer the user the proper physical need in order to keep them healthy. Users of prosthetics have been documented to suffer many health risks that are directly associated with the prolonged use of their aids. The concept mobility aid offers users a natural gait and reduced stress on the residual limb allowing them to use the device for extended periods with minimized risk of complications related to prostheses use.

Benefits Statement

As a concept, PACER offers the user many benefits that other prostheses don’t, including; spinal support/adjustment, superior quiet stance with lateral and medial control/anterior and posterior control, reduced stress on the residual limb with a suspended socket, and haptic feedback from the limb to the spine using the stretch reflex mechanism.

5.2 Design Criteria Met

5.2.1 Ergonomics

Human centered design was the foundation to the design process for Pacer, the end goal was to consider the user and their needs. The vest and spinal pack were designed to be able to adjust and move not only depending on the movement of the user but also dependent on the size of the user. Furthermore, some part of Pacer will be designed for the specific user to ensure a proper fit. The fit of pacer, like other prostheses, is dependent on a case by case basis. An ill fit could cause health complications.

The most notable feature of Pacer is the suspended socket. Users of prostheses develop many health complications because they tend to load the intact leg, which causes imbalances and greater wear and tear on the sides used. Pacer was designed to combat this. The socket liner is fastened into the socket housing which is snuggly strapped to the leg. This means pressure is already dispersed through the quadricep muscle. The socket housing is then mounted to the femoral support which has dampening motors in it allowing it to adjust as needed.

The support links to the hip pack, this allows the downward forces on the residual limb to be dispersed through the hip rather than completely on the joint itself. Those downward forces are then offset further with the spinal assembly and the vest. These component s work in tandem with everything else to allow those downward forces to be spread out over the back and core and shoulders. With conventional prostheses, again, there is a loading of a single leg. The user is forced to either lean to one side, or have their weight drop on their prostheses. Pacer returns the user to a more natural state, where standing, walking, and running are full body activities. Everything connects to everything else and works together.

5.2.2 Materials, Processes & Technologies

Many materials were considered throughout the design process to be potentially used in the final design of Pacer. Section 3.6.1 illustrated a detailed breakdown of materials and manufacturing methods. The breakdown highlights the use of aluminum and polymers to be the most used material. But also, the potential of conceptual material that is currently being used in other ways to create support structures for the human body. Furthermore, various material would be sourced from third party manufacturer, especially those that would require multiple parts for their assembly. These parts include shock absorption, computing, gyros, textiles, and motors.

The advancement of prostheses, mobility aids, and technology regarding balance control are all happening very fast some of these technologies include:

- Gyroscopic measuring
- Haptic sensory
- Spatial sensory
- Balance computing
- Lighter stronger materials

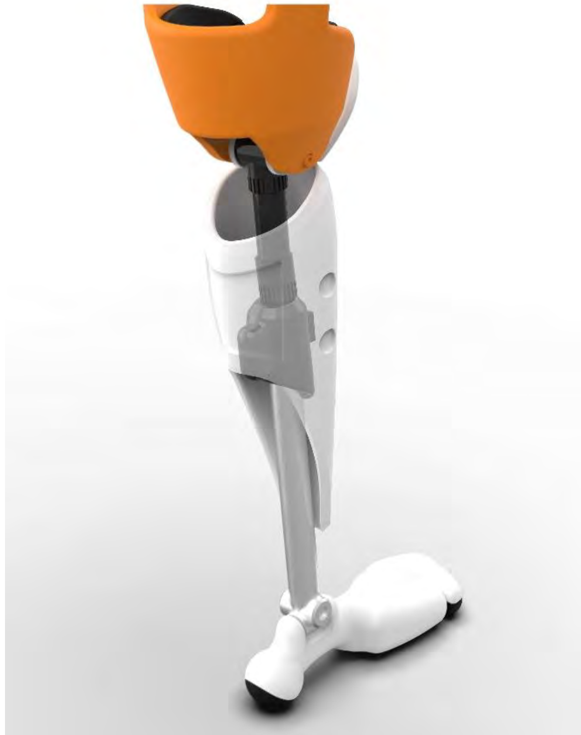
5.2.3 Manufacturing Cost Report

The manufacturing cost is estimated on items created on a bill of materials for section 3.6. see Appendix IV for the bill of materials. All costs in are rough estimates based on research conducted and experience.

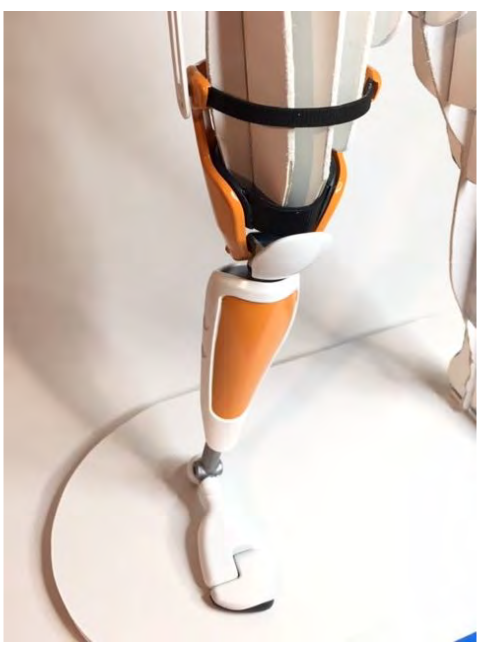
Part/Feature/description	***Material***	***Estimated price***
Pack connector	polymer	~$500
Lower spine motor	Various/polymer	~$500
Mid spine motor	Various/polymer	~$500
Upper spine motor	Various/polymer	~$500
Spine support pads left	Polymer	~$100
Spine support pads center	Polymer	~$100
Spine support pads right	Polymer	~$100
Lumbar support motor pack	Various	~$1,000
Cervical support motor pack	Various	~$1,000
Vest to spine connector	Various	~$200
Vest	Various	~$100
Vest breast pad	Various	~$50
Pack assembly	Various	~$5,000
Pack pad – lumbar	Polymer	~$300
Pack pad - hip – left	Polymer	~$200
Pack pad – hip – right	Polymer	~$200
Femoral hip structure	Calcium phosphate	~$2,000
Knee cap	Calcium phosphate	~$300
Leg structure/cover	Calcium phosphate	~$1,000
Joint assembly	Various	~$2,000
Joint nut	Aluminum	~$100
Tib/fib assembly	Aluminum	~$100
Socket	Various	~$1,500
Socket liner/pad	Various	~$3,000
Motor/suspension housing	Various	~$35,000
Heel pad	Polymer	~$150
Foot pad	Polymer	~$150
Toe pad	Polymer	~$150
Foot body	Various	~$3,000
Toe body	Various	~$2,000
TOTAL		~$60,800

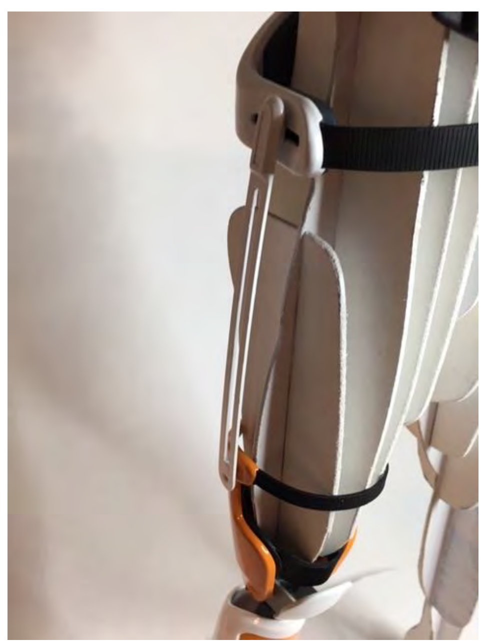
In conclusion the estimated cost of the complete mobility device, Pacer, will be approximately $60,800. As seen in table 3.6.2.1 of section 3.6 Commercial Viability, this would place Pacer at approximately the mid-range of the highest and lowest competitor products. This estimate was created by studying and comparing the prices of exiting products taking into account how state of the art some of the technology implemented is, the uniqueness of some materials, at full scale mass production, and that some processes/components may have to come from third party manufacturers.

5.3 Final CAD Renderings



5.4 Hard Model Photographs





5.5 Sustainability

The final design of this thesis project is a human centered design of a prosthesis and exoskeleton that focuses on key ergonomic features to enhance the user's overall quality of life and mobility. the final design will incorporate many sustainable aspects for health, safety and environment. The user's health will be addressed using the suspended socket system, reducing the risk of health complications associated with prostheses use. Safety is addressed by utilizing technology that aids in balance and gait control giving the user a more nature method of locomotion. Furthermore, users would receive training and rehabilitation with Pacer. The final design will also use sustainable materials to address environmental issues, as well as more durable materials, reducing the manufacturing needed for replacements and extending the lifespan of each unit.

Conclusion

The research and development presented in this chapter demonstrates that the final design fulfils the needs that were discovered in the problem, and fulfill the thesis requirements. Human ergonomics and sustainability played major roles in the fulfillment of the thesis requirements which were explored, thought out and designed appropriately for.

CHAPTER 6: Conclusion

6. Conclusion

In conclusion, the report is the culmination of research done on the topic of ergonomics for prostheses, mobility aids, and human beings; as well as the compilation of human centered design that went into this project.

Pacer is an innovative mobility aid for people who are living with lower limb amputations, this solution offers the user a more natural locomotion that gives them freedom through movement. This design integrates aspects of balance control, gait control, comfort, and promotes sustainability. Pacer offers the user a return to society without worry of not being able to care for one's self or missing out on being able to connect with others.

CHAPTER 7: References

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CHAPTER 8: Appendices

Appendices

Appendix I: Interviews

H - The only challenge with going up hills is your basically taking whatever you have left of your residual limb and doing a leg press of your entire body mass. I'm moving 190lbs uphill by moving a portion of leg that was designed to work with another portion. The prosthetic doesn't matter much going up hills cause you basically straight leg it. Do you have an example of "unstable" surface I could shed some light on?

H - And socket fit is very important as is the type of prosthetic and programming/alignment. All three work together to achieve the best results.

J - Unstable surfaces like the rocks you were traversing.

J - When you're approaching a hill from the top are there things you have to stop and consider?

J - From an observational standpoint it looks like you have to dig in with the heel a bit more.

H - If they're the large rocks I think your talking about, that would be a challenge for an able

Bodied person even. Rocks like a gravel drive way or job site are easy I do them all the time. Yeah when approaching a hill you may take a glance at it and pick your "line" of decent if there are obstacles to avoid, same thing anyone does really. And when the heel meets the ground going down hill, it takes 100% of my body weight and the hydraulic cylinder in the knee lowers me to the next step, then repeat. So it's not so much ad digging in the heel, but it's more the first part of the prosthetic that touches the ground and responds accordingly.

J - What are some measure you take when transferring from one foot to the other when heading down hill?

H - The knee bending does most all of the work it's actually very small movement from my residual limb. It's nothing I really have to even think about just something you learn over time.

J - How does maintaining balance over a slopes surface work/effect you? Is it drastically different?

J - Also, the turn at the bottom, do you find you favour a side when doing 180 turns? Would you mind running through that motion?

H - Balance while standing still on a slope is tricky, but possible. A lot of bilaterals tend to have a wide stance to balance easier but it's always more practical to keep your feet closer together. Not always possible. Also, there's a technique called “bobbing” basically moving back and forth, and even on uneven ground I can stay in one place basically still if I keep moving back and forth. Mostly used with stubbies but also with full length knees

And absolutely I favor one side. Just like being right handed, idk why but I always ride the resistance in my left knee and plant my right foot. Slight hills where I only need the resistance from one knee, 9/10 times I ride the left. Choice leg for going down curbs too. No clue why, just feels more natural. Most bilaterals would probably favor their longer/stronger long but mine are identical. Also, I probably favor my right leg to step up on curbs. Not sure why the preference on activity switches sides.

H - And yes while trying to come to an abrupt stop, or stopping from an incline there is the "pivot stop" movement. Basically plan your steps and placement and when the stop needs to Happen, the pivot leg (mostly my left) gets planted heel first and I ride the resistance of the knee into a pivot while landing on my hyperextended right leg. It's safe, comfortable, reliable, and very handy.

J - That's interesting, and how about moving uphill? What is the difference between that and downhill? Right off the bat I'm noticing the leaning forward. Why is that? To compensate for hip/knee action? Keep momentum forward? It interesting to watch because it looks like your hip is staying directly over the feet as your body leans forward.

H - Well in order to maintain comfortable balance your body bends in a < shape to keep your weight even, steep hills it definitely helps with momentum. Going down is low body work, the prosthetic does the work with hydraulic resistance to lower you, it just takes practice. Going up hill is near the opposite, all body work. With no knee left on my stumps, my hip joint does all the articulation.

H - Going up hill it’s best practice to keep your feet together and lean forward, take small manageable steps. Most bilaterals tend to keep a wide stance going up hills too, biting off bigger steps then they can handle. Also Looks unnatural.

Appendix II: User Observation

Objectives

Needs Statement

Mobility for those with disabilities, namely lower-limb amputation, is a purposeful activity based on ease of functioning, increased safety, return to independence, and comfort afforded to the amputee. While esteem can be returned by styling and quality cues of devices concerning mobility; the actual act of mobility is a social one. The ability to get up and go allows for not only interaction with their environment, but also promotes interactions with other humans. Control and mastery of such devices is related to the performance of the machine being used, but also the comfort it affords the user while in use; greater comfort results in better mobility and therefore improved independence. The value being created by mobility devices is not directly the user being able to move or have improved mobility, but the regained independence.

Description

The purpose of doing user observations, both in person and through research, is to achieve a deeper understanding of the user and their needs. In mobility of lower-limb amputees this means understanding how they move through space currently and what kinds of challenges they face because of the physical impairment. Having an understanding of their movement and challenges will aid in the creation of a well thought out and useful design. Using evidence-based research while focusing on the important aspects of human centered design, user experience and ergonomics.

Research Objectives

The objective of this report is to observe the primary users' mobility in environments that will help create a better understanding of needs to be met, help drive design decisions, and further enforce thesis topic feasibility. Areas of focus for the user observation will include but not be limited to current mobility practices concerning methods in which the human body has adapted to its environment/new method of motion, touchpoints, ergonomics, human lifestyle, interaction/experience and the effects it has had on the primary user. Observations will be made without any predetermined assumptions in order to track the research without an existing bias or thought.

Key Activities

The first video will be acquired from online sources focusing on 'day in the life' scenarios, affording a deeper understanding of day to day activities the user will face regularly such as mobility around the house or preparing for departure from living space. The second video will be acquired from an interview participant, and then will be reviewed and analyzed on a in person basis on Saturday, October 26, 2019. This video will demonstrate and extreme case in mobility that pushes and amputees' body harder than most other movement. Having an understanding of the extreme conditions faced by the primary user will help drive design incites concerning touchpoints, ergonomics and other human factors.

Target Users

Primary users are people suffering from an amputation of either one or both lower extremities, either above knee (AKA) or below knee (BKA), due to health complications or trauma as represented by research to be relatively close in regards to major causes of amputation. With 47% due to traumatic incident and 52.3% due to health complications. The primary user has a mean age of 56 years, but user profiles will also focus on user of 40 and younger due to their physical lifestyle and need to grow with an amputation which has long term effects on the body. The Primary user is mostly male and would use/wear a prosthetic regularly for most daily activities for approximately 13-18 hours of the day and has expressed that wearing a prosthetic has made residual limb pain and joint pain worse. The primary user is considered skilled or proficient in using the prosthetic.

User Environment

The environment observed in the first video is a typical home setting where the user will have to maneuver through obstacles found in everyday life such as off the bed, into the shower, and around the kitchen. The predetermined assumption is that the user will need a lot of touch points for leaning in order to be able to use their hands in these spaces. The environment observed in the second video is outdoors on a sunny day. The participant is utilizing a grassy hill that as a steady incline that increases in severity of it angle towards the top. This is not a typical environment for prosthetics users and would normally be avoided due to high chance of a fall to occur. The ground will be softer on concrete and may play a role in the participants ability to dig in for traction. Though the grass looks dry it is still significantly more slippery than concrete.

Preliminary Video Observation

2.1 Preliminary Scoping

Video #1
URL: https://www.cbc.ca/news/canada/british-columbia/amputee-claims-discrimination-after-airport-security-takes-batteries-1.5109369

Title: Forced to Crawl

Length: 3:18

Brief Description: Stearn Hodge demonstrates how he was forced to crawl on his holidays, after United Airlines and an airport security agent seized the batteries needed for his portable scooter.

Relevance to Thesis Topic: Shows how those with amputations face various mobility challenges, without aids or devices mobility becomes physically demanding.

Video #2
URL: https://www.youtube.com/watch?v=7KILUvJuP-Y

Title: Bilateral Above Knee Amputee Getting Up from The Floor Demonstration

Length: 1:35

Brief Description: Hayden demonstrating several techniques for getting down to the kneeling position on the floor and also raising up to the standing position. He is using the older Ottobock C-Leg knees.

Relevance to Thesis Topic: As an amputee, taking a fall is not only very likely but also very dangerous and likely to lead to injury. Most amputees struggle in recovery efforts post fall, understanding methods and techniques for recover may help influence design ideas/Human

2.2 Video Observation

Contributor: Pnina Ullrich **Date posted:** Oct 2, 2016 **Title:** Morning Routine of an Amputee

Length: 5:57 min **URL:** https://www.youtube.com/watch?v=DMsgIjK81Rk

User Experience Chart

Video #3
URL: https://www.youtube.com/watch?v=DMsgIjK81Rk Title: Morning Routine of an amputee Length: 5:57 Brief Description: woman goes through regular morning tasks from getting up in the morning to putting away dishes after breakfast. Relevance to Thesis Topic: Shows patterns and routines from the perspective of an amputee. Shows touchpoints and methods/techniques amputees implement to make life easier/human factors.

1.Getting up from bed

amputation during sleep effects the bodies ability to move or rotate. amputation in image is resting on top of the other leg. pillows along wall may be there to help support the body during sleep.

2. Donning Device

bed is low enough for user to be able to bend to ground level. crutches are left on the floor for easy access.

3. Shower (wet surfaces)

shallow shower for ease of access. user needs a shower seat in order to be able to bathe. user also placed a towel on the shower floor creating a non-slip surface.

4. Manual Dexterity

both hands are free while at sink. user has crutches beside sink. user is blancing infront of sink with some moments leaning on the sink.

5. Devices and Dexterity

one cruth is leaned on counter nearby for easy access while other arm and leg are supporting the body. free hand is performing the necessary tasks.

6. Carrying Objects

user requires both cruthes in order to move effectively. user is able to precariously balance on the crutch handles with objects in hands allowing her to move and carry things from one location to another.

7. Releasing Objects

high level of dexterity is shown by the user when she lets down the plate in hand then moving fingers to crutch handle to re-grip. user is leaning over seat bearing full weight on one leg. arm in the back is acting as a counter balance.

8. Navigating with Devices

navigating some droors and cupboards requires high lebvel of dexterity in that the user is balancing on one leg, while using a couple finger on one hand to locate objects and control the crutch grip.

9.Manual Dexterity (low)

crutch is leaning on counter, opposite hand is stabalizing the body with the other leg. free hand performs tasks. wrist loop of crutch is able to hang freely allowing the hand to stabalize the body using the counter.

10. Making bed/Leaning

user is able to use both hands while stabalizing the body using the knee to lean on the bed. the goot is angled allowing it to sit directly under the body on the center line.

11. Tiding (low)

user is supporting her whole weight in a squat-ing position. left hand is opperation both crutches leaving the right hand free aloowing her to perform tasks.

12. Manual Lifting (low)

performing tasks at a lower level with a heavier obects requires more support. in this example the user needs to sit while operating a bag of dry cat food, pouring it out into a bowl on the floor. she would otherwise have a lot of difficulty doing this task.

Key Activities

Activity 1: Manual Dexterity

In this case the user uses hand crutches in order to move around. But leaning or balancing is a major factor in order to maintain use of both hands. Without these actions the user would be left without the use of her hands or with the use of only one hand limiting her manual dexterity severely

Activity 2: Shower/ Wet Surfaces

Wet surfaces turn into major hazards for those left with a single appendage and or standing on two prosthetic legs. With limited balance control the user is left susceptible to a fall. Wet surfaces pose as threats in other areas as well such as wet cement, tiles, and even some rubber mats. The user is seen here placing a towel on the shower floor in order to provide additional grip.

Activity 3: Navigating with devices/carrying items

The user is seen here completing various tasks of manual dexterity while navigating her apartment with her crutches. She can be seen opening and closing cupboards while removing objects. Sha can also be seen holding a plate while using her crutches then offloading it on the table.

Activity 4: Manual Lifting

The user can be observed manually manipulating a moderately heavy load. The cat food she lifts and pours cannot be don’t from a standing position. The user needs to sit in order to not only lift the load but pour it and put it away. Assumptions are that the load would offset her balance.

Summary:

The user heavily relies on the use of her crutches in order to maintain balance and control of her body. When she isn't using her crutches, she is seen leaning on objects and surfaces in order to regain control of her body. Loss of this balance would result in a fall. She is seen performing tasks at a high level of mobility and manual dexterity. Though she is slowed down by needing to free her hands for complex tasks. When carrying lightweight objects, she can be seen carrying them while operating her crutches, then being able to put said object down with minimal effort. Her most notable concern isn't that she isn't able to perform the tasks, but that she is required to release her crutches for complex tasks. She is seen as being able to adapt to her amputation and the way that it limits her, even by improvising safety precautions for herself like the towel on the shower floor.

Appendix III: Product Research

Objectives

To review comparable products in the marketplace

To determine the features and benefits for the products

To assess competitor benefits to help define possible design niches

To draw conclusions that will 'inform design'

Thesis Topic

The topic for this thesis is mobility of amputees.

Section 1. Benchmarking I – Generating a Table Comparing Main Features

Method

Promotional media (literature/internet) of competitor products are researched and evaluated to determine features and benefits, and their relative importance to design of a new product. In some cases, products were selected on the basis that they had met similar user needs as the thesis topic, but may have differed substantially on other needs.

Competitors

The following is a list of products that are similar in user and or function, they range from powered to non-powered in a variety of materials, range of motion, size, and function. These competitors will serve as a basis for understanding the potential and current competition to this thesis project outcome.

Table 1.

Product Benchmark List			
1	EKSO Bionics – Ekso Vest	7	Cyberdyne – HAL Lumbar Type for Well
2	SUITX – BackX	8	INNOPHYS – Muscle Suit

3	SUITX – LegX	9	INDEGO – Indego Therapy
4	SUITX – ShoulderX	10	SKI-MOJO – Skimojo Gold
5	SUITX – PHOENIX Medical Exoskeleton	11	RB3D – Hercules
6	Cyberdyne – Lower Limb Type	12	---

Evidence

A Table comparing the main features for 8 of the 11 comparable products was constructed. The main features chosen for comparison were:

User Weight Max

Driving Force (motorized/battery)

User Height Range

Assistive Force

Water Resistance

Operating Time

Links with User

Materials

Unit Weight

Feature Comparison Table

								
Ma x User Weight	N/ A	N/A	N/A	40k g~100kg	40 – 80kg	N/A	250 lb (113 kg)	60 - 100kg
Dri ving Force	N on-Powered	Non -Powered	Mot orized/ Batt ery	Mot orized/ Batt ery	Mot orized/ Batt ery	Compr essed Air	Mot orized/ Batt ery	Mot orized/ Batt ery
Use r Height Range	5’ 0” – 6’4” (152 – 193 cm)	hei ght and waist sizes (5%-95% of human dimensions)	Vari able	150 - 200cm	140 - 180cm	*Small/ medium* size: 150 cm to 165 cm (4" 11' to 5" 9') *Medium/large* size: 160 cm to 185 cm (5" 3' to 6")	5'1" – 6'3" (155 – 191 cm)	N/A
Ass istive Force	5- 15 LB. lift assist per arm	Red uces compression on the spine at L5/S1 disc by an average of 60%	spe ed of 1.1 miles/hour (0.5 m/sec), Vertical support	hip joint: extension 20˚/flexion 120˚ knee joint: extension 6˚/flexion 120˚	hip joint: extension 30˚/flexion 130˚	Back - Up to 35.7 kgf (140 Nm) = 78.7 lbf (103 ft-lb)	Vert ical support	allo ws most trips: walk flat or on slopes up to 10 °, climb stairs, get into squatting or sitting position.
Wat er Resistance	Y es	Yes	Yes	No	Yes	Yes	yes	yes
Op erating Time	U nlimited	Unli mited	4-8 hours	1 hour	4.5 hours	Depen dent on use	2 hours	4 hours
Lin ks with User	W aist, back, shoulders, arms	Wai st, back, shoulders	Hip, back, shoulders, knees, Shins, Feet	Hip, back, shoulders, knees, Shins, Feet	Wai st, Lumbar, Quads	Waist, back, shoulders, Quads	Hip, back, shoulders, knees, Shins, Feet	Hip, Feet
Mat erials	N ylon, Aluminum, Rubber	Nyl on, Aluminum, Rubber	Nyl on, Aluminum, Rubber,	Nyl on, Aluminum, Rubber,	Nyl on, Aluminum, Rubber,	Nylon, Aluminum, Rubber, Polymer (high impact)	Nyl on, Aluminum, Rubber,	Nyl on, Aluminum, Rubber,

			Polymer (high impact)	Polymer (high impact)	Polymer (high impact)		Polymer (high impact)	Polymer (high impact)
Uni t Weight	9. 5lb. (4,3kg)	4.9 lb (2.2 kg) and it is worn with an Exoskeleton Harness that weighs 2.5 lbs (1.1 kg)	12. 25kg (27 lbs)	14k g	3.1 kg	4.5 to 6.6 kg (14.6 lb.)	39 lb (17. 7 kg)	30k g

Table 2.

Table 3.

Design Elements Comparison Table								
								
Overall Form (categories below reflect type of product selected)								
Shape Geometric (Rectilinear, Ellipsoid, Cylindrical etc)	C ylindrical	N/ A	Ell ipsoid, Cylindrical	Ell ipsoid, Cylindrical	Ell ipsoid, Cylindrical	N/A	Ellip soid, Cylindrical	Rec tilinear
Repetition Arrays of holes Arrays of lines	St raps/ S upports	St raps	Br aces, joints	Br aces, joints	Br aces,	Bra ces, Straps, Supports	Bra ces, joints	Bra ces, joints
Pattern	N/ A	N/ A	N/ A	N/ A	N/ A	N/A	N/A	Blu e Stripe
Balance (symmetry etc))	Le ft mirrors Right	Le ft mirrors Right	Le ft mirrors Right	Le ft mirrors Right	Le ft mirrors Right	Left mirrors Right	Left mirrors Right	Left mirrors Right
Interface Comparison Table								
Buttons / Dials	N/ A	N/ A	N/ A	S oft touch buttons	N/ A	N/A	Butt ons for Assisted walk	Po wer
Light indicators	N/ A	N/ A	N/ A	P ower/	N/ A	N/A	Butt ons light up	Po wer/ Battery

				B attery				
Touch interface	N/A	N/A	U/I	N/A	N/A	N/A	N/A	N/A
Other	N/A	N/A	N/A	LED screen	N/A	N/A	N/A	N/A

Promotional literature for these products is shown in appendix 1

Conclusion

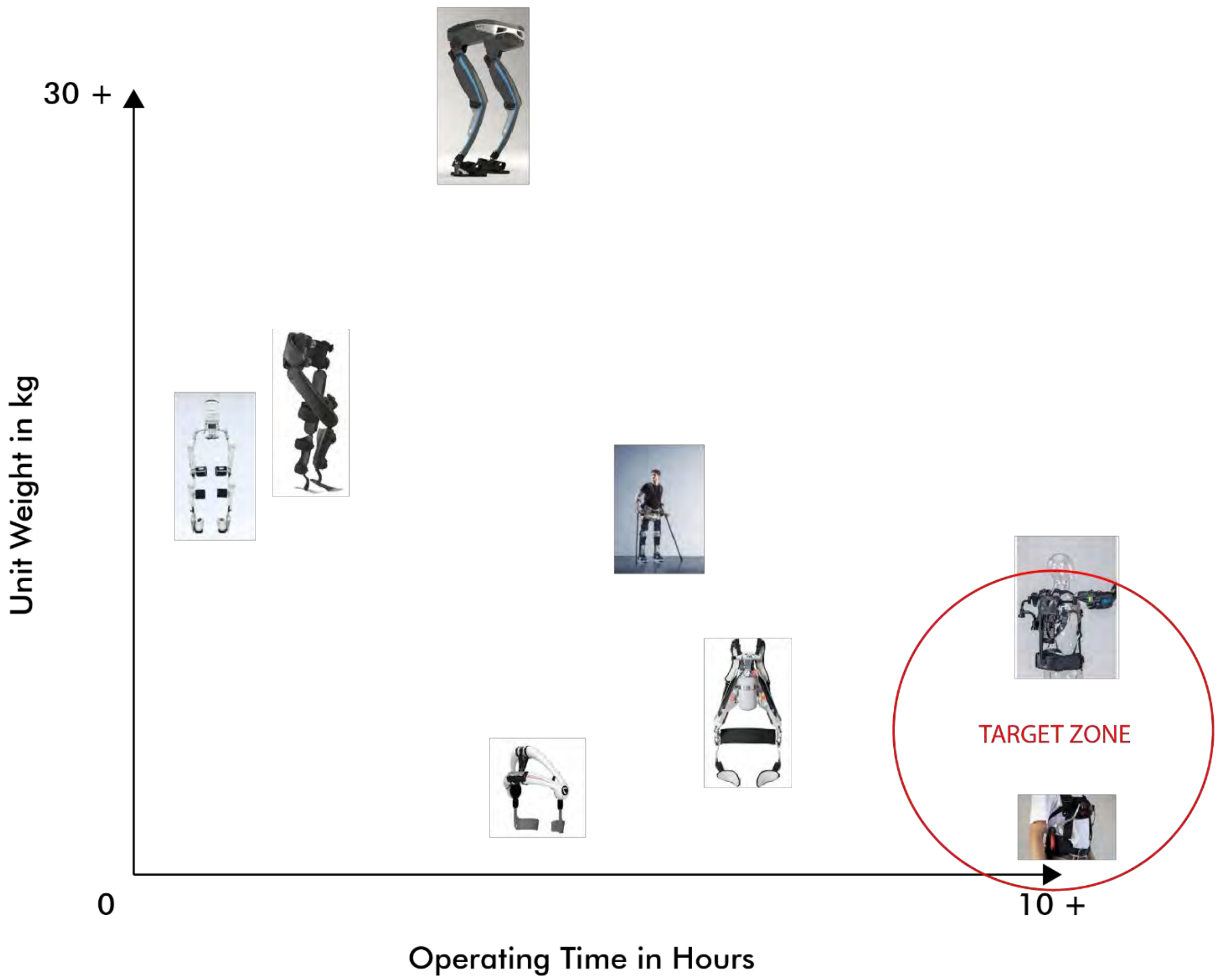
While the variety of products available is large, most products tend to be cumbersome or limited in modularity. Operating time is low depending on amount of use by user and type of technology implemented. Opportunities exist in making mobility products lighter, smaller, and being less obtrusive. Advancements in tech afford ability to make these products more accurate, modular, stronger, and hidden.

Section 2. Benchmarking II – Comparing Pairs of Features on an X-Y Graph

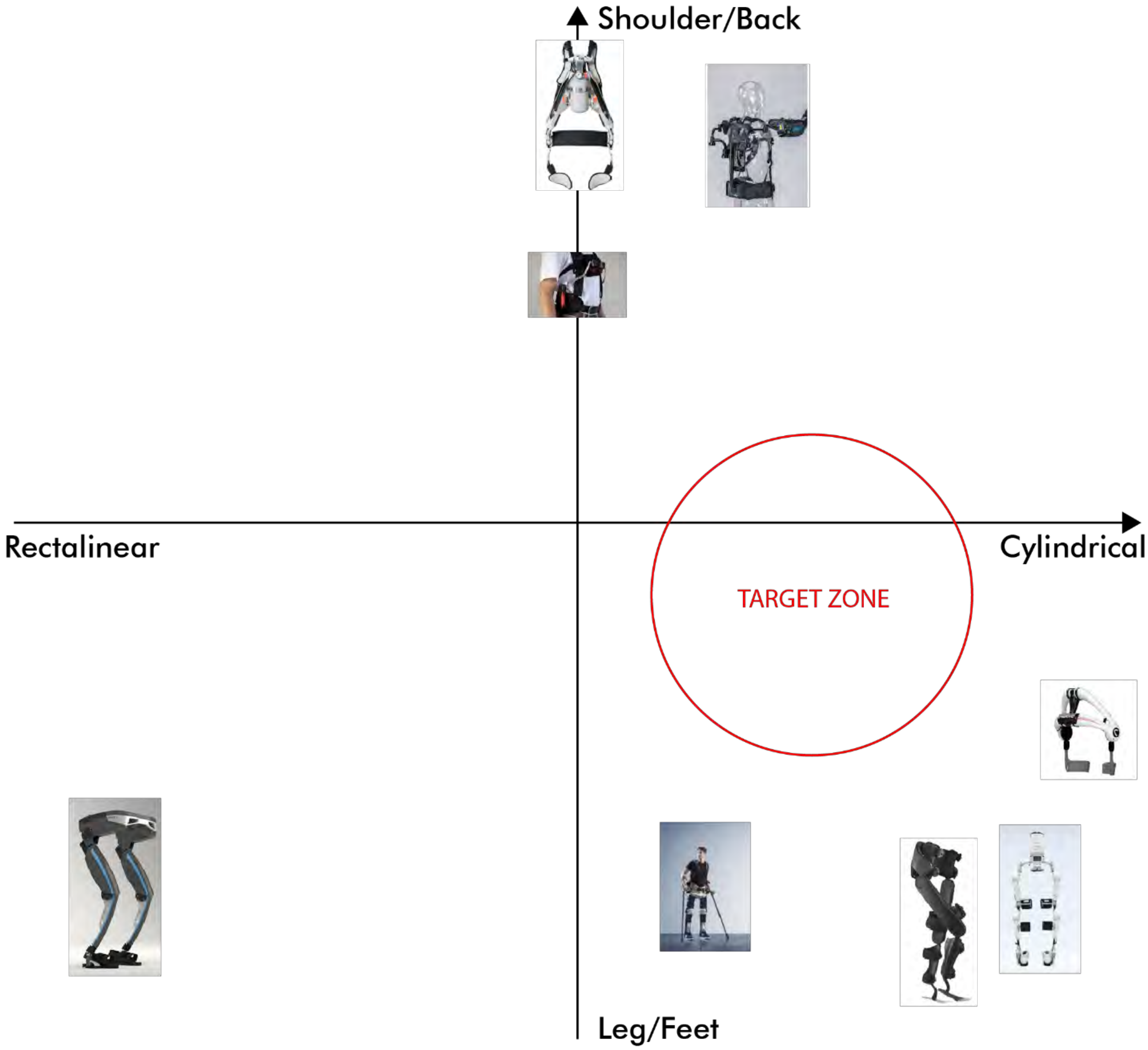
2.1 Method

Pairs of features were selected to create X-Y graphs. The paired features were assigned to either the X or Y axis, images of each of the comparable products placed on the graph. The intent is to see if patterns emerge which could indicate a zone of opportunity in the market. The first graph compares unit weight to operating time. These were chosen to see if there is any correlation between how heavy the mobility device is and how long they are able to operate for. The second graph compares elements of design and location of contact points. These were chosen to identify if the form is informing the location and or use of each device, and where there might be opportunities for design and market niches.

2.2 X-Y Graph 1



2.3 X-Y Graph 2



2.4 Conclusion

Exoskeletons are a secluded and specialized market due to healthcare aspect and number of companies designing and producing these types of products.

The first graph shows a pattern where the weight directly affects the operating time. The trick is to design an effective product that is light and has a long time of operation, while still integrating tech.

Most current products lean towards designs that lend to organics and anthropometrics.

Current design is clunky and cumbersome

Products that concern leg support are generally bulky while upper body and more slim

Opportunity in designing a product that is sleek for both upper and lower body.

More opportunities may lie in power options and cost benchmarking.

Section 3. Benchmarking III – Determining Main Benefits and Features of Comparable Products

3.1 Methods

Determining the features and benefits for a product or related product is key to inform design and user needs. Using promotional material for all 11 products related to the thesis topic; where the frequency of descriptive words is compiled and recorded, then organized as the top 5 most common words used in those related products.

Benefits are the hooks that catch the customers and makes them want a product over competing products. Benefits describe how a product will aid the user in performing tasks or making the product sound more exciting.

Features are technical information/stats that inform the user of a products capabilities and or composition.

3.2 Key Benefits

Top 5 words associated with benefits, as determined from promotional materials. Listed as follows

Table 4.

Key Benefits of Comparable Products	
1	Comfort
2	Support
3	Reduction of Injury
4	Control/Function
5	Reduction of Forces

3.3 Key Features

Top 5 words associated with features, as determined from promotional materials.

Listed as follows

Table 5.

Key Features of Comparable Products	
1	Weight
2	Adjustable
3	Power/Rechargeable
4	Assisted Force
5	Modular

Section 4. Summary/Discussion

4.1 Overall Feature Comparison

Two Products close to the ‘design opportunity’ on graph 1 were assessed and compared on how they met customer needs. The two products selected were:

EKSO Bionics – Ekso Vest

SUITX – BackX

4.2 Features Comparison

Results are seen in the table below. Benefits are identified for this product based on previous sections. Possible niche markets are deficits in current product offerings.

Table 6.

Features	Features Comparison		
	EKSO Bionics – Ekso Vest	SUITX – BackX	Possible Niche Market
Weight	Good	Great	
Adjustable	Good	Good	
Power/Rechargeable	Poor	Poor	X
Assisted Force	Fair	Poor	X
Modular	Poor	Fair	X

Section 5. Summary/Discussion

5.1 Key Benefits, Features

A side by side comparison of key benefits and features, as determined by promotional materials highlighted in the tables below.

Table 7.

Key Benefits of Comparable Products	
1	Comfort
2	Support
3	Reduction of Injury
4	Control/Function
5	Reduction of Forces

Key Features of Comparable Products	
1	Weight
2	Adjustable
3	Power/Rechargeable
4	Assisted Force
5	Modular

5.2 Updated Needs Statement

Design a lightweight, modular mobility device/product for amputees that will fit a wide range of body types, while improving the way they move through physical space. This Device should explore ways to improve comfort, support, safety, control, and reduction of forces.

Appendices

Appenix 1.

PRODUCT 1: EKSO Bionics – Ekso Vest

https://eksobionics.com/eksoworks/eksovest/

Description - EksoVest is an upper body exoskeleton that elevates and supports a worker's arms to assist them with tasks ranging from chest height to overhead. It is lightweight and low profile, making it comfortable to wear in all conditions while enabling freedom of motion.

The Specific Worker (SW) EksoVest is one (1) device assembled with a single set of components to fit the measurements of an individual. This includes the base device along with: one pair of arm cuffs, one pair of upper arm straps, one hip belt, and one pair of springs. You must use our measurement guide in the Operator Manual to submit your component sizes when purchasing a Specific Worker Device. This kit has a lower price due to the fewer number of components included. We recommend purchasing these SW kits for individual operators after completing in-house trials with our GC kits that can be adjusted to fit different size workers.

Note: you can always purchase additional components for your SW EksoVest to adjust the fit for a different sized operator.

Figure 0-1 -

https://eksobionics.com/eksoworks/eksovest/

SPECIFICATIONS:

5-15 LB. lift assist per arm

lift force can be adjusted to fit application and operator preference

Reduced fatigue & increased endurance

operators become less tired over the course of their shift leaving them with more energy at the end of the day

Rugged design. Built with durable materials and tested to withstand wear & tear on the job

Customizable size. Eksovest can be adjusted to provide a custom fit to a wide range of operator sizes

Healthier workers

lessening the strain on operators' shoulders and back reduces the likelihood of on the job injuries

Improved worker morale reduction in fatigue and injury leads to happier workers and improved worker retention

Unit weight: 9.5lb. (4,3kg)

Worker height range: 5'0" – 6'4" (152 – 193 cm)

The General Configuration (GC) EksoVest is a full kit that includes all available components for one (1) device. This includes the base device along with: three pairs of arm cuffs (S, M & L), three pairs of upper arm straps (S, M & L), two hip belts (S/M & L/XL), the hip belt extender, and four pairs of springs (Levels 1, 2, 3 & 4) along with storage bags for the extra components when not in use. This kit has a higher price due to the additional components included. We recommend purchasing these GC kits first so you can try out EksoVest with multiple operators of different sizes for your application and then purchasing additional SW kits for individual operators as needed.

PRODUCT 2: SUITX – BackX

https://www.suitx.com/backx

backX is a novel industrial exoskeleton that substantially augments its wearer and reduces the forces and torques on a wearer's lower back region (L5/S1 disc) by an average of 60% while the wearer is stooping, lifting objects, bending or reaching. backX augments the wearer's strength and can reduce the risk of back injuries among workers. Designed for all-day wear, backX never impedes natural movements and the wearer can walk, ascend and descend stairs and ladders, drive automobiles, ride bicycles, run and perform any maneuver with absolutely no restriction.

Figure 0-2

https://www.suitx.com/backx Features

REDUCE BACK STRAIN: Reduces compression on the spine at L5/S1 disc by an average of 60%

ZERO IMPEDANCE: Ascending and descending stairs and ladders, running, driving, and biking are completely unimpeded

RUGGED: Designed to withstand harsh industrial environments, backX is WATERPROOF, DUSTPROOF, and easy to maintain

NO BATTERIES: Cleverly designed to reduce the risk of back injuries without the use of batteries, actuators, or computers

LOW PROFILE: Follows user's body to fit in tight spaces and changing environments

COMFORTABLE: Good for all day use. Minimal inhibition of arm, leg, and torso range of motion

QUICK DONNING AND DOFFING: backX can be put on and taken off in less than 30 seconds

COMPATIBLE: Works with safety harnesses, tool belts, and can be worn under reflective vests and work jackets

ADJUSTABLE SIZE: Fits a wide range of height and waist sizes (5%-95% of human dimensions)

ADJUSTABLE SUPPORT: Support force can be quickly changed by the user to accommodate different tasks, and fatigue level

OPTIMIZED SUPPORT: Support force is optimized based on bending angle. Does not impede non-bending tasks

MODULAR: Can be worn with shoulderX and legX

MODEL S: Both models can be worn by itself. Model S is compatible with **legX**

Model S hardware weighs 4.9 lb (2.2 kg) and it is worn with an Exoskeleton Harness that weighs 2.5 lbs (1.1 kg)

Model S features a frame design that keeps the rear belt open and accessible when reaching for tools.

MODEL AC: Model AC is compatible with both legX and shoulderX

Model AC hardware weighs 7.5 lb (3.4 kg) and it is worn with an Exoskeleton Harness that weighs 2.5 lbs (1.1 kg)

Model AC frame is load-bearing: the Model AC will transfer the weight of attached loads directly to the hips (analagous to a backpack waistbelt) or to the ground if legX is attached.

PRODUCT 3: SUITX – LegX

https://www.suitx.com/legx

legX is a revolutionary knee exoskeleton that allows the wearer to squat repeatedly or for prolonged periods of time by reducing the knee joint and quadricep muscle forces. The amount of support can be adjusted to suit the needs and weight of the user. The legX is offered with a custom work boot to maximize user comfort. This intelligent system can distinguish between walking, ascending/descending stairs and squatting to allow unimpeded locomotion and only provides support when support is desired. legX also has a locking mode, where the exoskeleton can be used like a chair. An anthropomorphic profile and adjustable sizing allows for natural movement and intuitive awareness of one's position within tight spaces. legX moves freely with a worker without impeding the wearer while providing support during squatting tasks.

Figure 0-3 https://www.suitx.com/legx

Features

REDUCES KNEE FATIGUE AND FORCES: Substantially reduces effort of the knee muscles, thus reducing knee joint force.

INTELLIGENT: Can distinguish between walking, ascending/descending stairs and squatting to allow unimpeded locomotion and only provides support when support is needed.

ZERO IMPEDENCE: legX does not impede common day-to-day activities such as ascending and descending stairs, and even driving or biking. legX moves freely with a worker without impeding the wearer while providing support during squatting tasks.

COMFORTABLE: An anthropomorphic profile and adjustable sizing allows for natural movement and intuitive awareness of one's position within tight spaces.

WORKS WITH EXISTING GEAR: legX can be used with tool belts and safety harnesses allowing standard worker equipment to retain its existing functionality.

COMPATIBLE: legX can be used in combination with backX to provide additional support and is part of the entire MAX system when combined with the backX and shoulderX.

ADJUSTABLE SUPPORT FOR THE USER: The amount of support can be adjusted to suit the needs and weight of the user.

LIGHTWEIGHT: Pair of legs weigh 13.7 lbs (6.2 kg). The weight of the device is not borne by the user.

ADJUSTABLE SIZE: legX is adjustable to various sizes and can be worn all day.

Numerous uses of legX at various sites

Workers in jobs with a high risk of knee injury share common experiences; they all perform repetitive squatting or endure prolonged periods of time in a squatting posture. legX is designed based on solid engineering foundations at the University of California, Berkeley and suitX with close attention to workers' needs and feedback.   legX have been used in numerous industrial applications as shown below.

PRODUCT 4: SUITX – ShoulderX

https://www.suitx.com/shoulderx

Figure 0-4
https://www.suitx.com/shoulderx

shoulderX V3 is the world's most advanced shoulder-supporting exoskeleton for use by automotive, construction and shipbuilding workers. shoulderX augments its wearer by reducing forces at the shoulder complex, substantially reducing the risk of shoulder injuries and increasing workplace productivity.

The third-generation industrial exoskeleton incorporates novel features based on the feedback obtained from numerous field evaluations across the globe. shoulderX V3 introduces a novel human interface technology that can automatically conform to each user's unique body shape to achieve an impeccable fit and unparalleled comfort. This interface provides a firm fit to the user, reducing slippage (sagging) between the wearer and the exoskeleton and, hence, reducing the need to perform micro-adjustments of the device during use, as commonly observed in other devices. Additionally, this interface provides superior breathability and has an exceptional ability to remove heat from the user, thereby maximizing user comfort. shoulderX V3 reduces the inventory a customer must manage to support their workforce by providing these key features: First, it is fully adjustable making it a "one-size-fits-all" wearable exoskeleton, resulting in a single unit addressing the needs of users of various shapes and strengths; second, this novel exoskeleton provides a wide range of strength output through a tool-less adjustment mechanism and it does not require multiple cartridges or gas springs. The third generation of shoulder-supporting exoskeleton boasts a 40 percent reduction in weight by use of carbon fiber without losing any of its industry-leading characteristics and range of support strength. Like its predecessor, the new design does not use electric power, does not need batteries, is available in multiple configurations such as fire retardant, dust-proof and water-resistant and is specifically designed to withstand extremely harsh environments such as construction sites and shipbuilding facilities.

Features and Benefits

ADJUSTABLE SUPPORT: Support capacity can be quickly changed to accommodate different users, tools, tasks, and fatigue level.

OPTIMIZED SUPPORT: Support force gradually increases as the user lifts his arms and becomes near zero when the arms are lowered, allowing the user to rest arms naturally or reach for tools on their tool belt.

ADJUSTABLE SIZE: Fits range of worker height, waist size, shoulder width, chest depth, and arm length (5%-95% of human dimensions)

ANTHROPOMETRIC PROFILE: Follows user's body to fit in tight spaces and changing environments

LIGHTWEIGHT: shoulderX weighs 7 lbs (3.17 kg)

BATTERIES NOT REQUIRED: Cleverly designed to reduce the risk of shoulder and arm injuries without the use of actuators and computers

RUGGED: Waterproof, dustproof, and easy to maintain

COMFORTABLE: Minimal inhibition of arm and torso range of motion. Designed for all-day wear

MODULAR: One or two arm use, compatible with legX.

COMPATIBLE: Compatible with tool belts, allowing workers normal equipment to retain functionality

Quick Donning and Doffing: Less than 1 minute to put on or take off

Competitive Edge

Unlike other devices in the market, shoulderX does not require additional hardware (cartridges, cassettes, springs, etc.) to adjust shoulder support strength. This eliminates the risk of losing components and eliminates the need to coordinate and carry additional components.

Unlike other devices that protrude significantly behind its user, shoulderX has a slim profile that allows it to be used in confined spaces and reduce the risk of bumping into surrounding objects or personnel.

PRODUCT 5: SUITX – PHOENIX Medical Exoskeleton

https://www.suitx.com/phoenix-medical-exoskeleton

Figure 0-5 https://www.suitx.com/phoenix-medical-exoskeleton

The PHOENIX Medical Exoskeleton is the world's lightest and most advanced exoskeleton designed to help people with mobility disorders to be upright and mobile. In the clinic, at home, and in the workplace Phoenix has successfully enabled many individuals to stand up, walk about, and speak to peers eye-to-eye. Phoenix has only two actuators at its hip; the knee joints are designed to allow support during stance and ground clearance during swing. Phoenix is considered an investigational device and currently not available in the United States.

Major Features of PHOENIX:

A modular exoskeleton allowing the user to independently put on and remove each piece.

Weighs only 12.25kg (27 lbs), affording greater agility.

A speed of 1.1 miles/hour (0.5 m/sec) has been clocked by a Phoenix user. However, the maximum speed depends on the individual user.

On a single charge, Phoenix can walk for 4 hours continuously or 8 hours intermittently.

Phoenix is adjustable for different size users and can be easily configured to fit individual conditions.

An intuitive interface makes it easy for users to control standing up, sitting down and walking.

Phoenix can comfortably be worn while seated in a wheelchair.

PRODUCT 6: Cyberdyne – Lower Limb Type

https://www.cyberdyne.jp/english/products/fl05.html

Figure 0-6
https://www.cyberdyne.jp/english/products/fl05.html

Cyborg-type robot fulfills wearer's will to stand and walk.

HAL for Well-Being Lower Limb Type Pro is a wearable robot designed for inducing the improvement of the physical function in the lower limb, for the wearer in chronic stages. Various upgrades were applied to this device, compared to its previous model, HAL for Well-Being Lower Limb Type.

SPECS and FEATURES

External dimension	length 430mm x width 470mm x height 1,230mm [*1]

Weight Double-leg model/approximately 14kg

*2

Single-leg model/approximately 9kg

*2

Movable range hip joint: extension 20˚/flexion 120˚

knee joint: extension 6˚/flexion 120˚

Weight limit 40kg~100kg

Operating time approximately 1 hour

※3

Power source custom battery

*1

Dimension of S size unit, on the shortest setting

*2

Includes cuffs, sensor shoes and batteries

*3

May differ subject to operating environments and conditions

*

The product is designed for the wearer who requires support due to difficulties standing, sitting and walking. As the device uses bio-electrical signal to support the movement, if bio-elecrical signal cannot be detected, the device will not support the wearer with the intended movement. In this case, the wearer may not use the device.

Size	S Size	M Size	L Size	X Size

Height [approximately]	150~165cm	160~175cm	170~190cm	180~200cm
Upper leg length	36~38cm	38~41cm	40~45cm	43~48cm
Lower leg length	35~38cm	37~41cm	39~45cm	42~48cm
Hip width	M Size		W Size	
	28~36cm		32~40cm	
Shoe Size	23.0, 24.0, 25.0, 26.0, 27.0, 28.0, 29.0, 30.0 cm			

PRODUCT 7: Cyberdyne – HAL Lumbar Type for Well Beinghttps://www.cyberdyne.jp/english/products/bb04.html

Figure 0-7 Beinghttps://www.cyberdyne.jp /english/products/bb04.html

New HAL for realizing Zero Burdening-care Society

HAL Lumbar Type Well-being (BB04) is a Wearable Cyborg that could be applied for two roles. The device supports both caregiver and care-receivers. When it's used by "caregiver" it reduces the stress applied on the lumbar region during care movement and reduces the risk of back injury. When it's used by "care-receivers", it could help a person with weak legs to maintain and improve his/her body function.

Reduction of physical burden of caregivers leads to improvement of labor environment and prevention of work accident. Additionally, enhancement of independence of care-receiver, such as sit to stand action without support reduces burden of the person himself/herself, but also significantly reduce the burden of caregiver. Double role of new HAL will approach solving the issues of aging society in two-ways, leading to realization of Zero Burdening-care Society.

applicable range of height (approximate)	140 ~ 180cm
applicable range of weight (approximate)	40 ~ 80kg
abdominal girth	less than 120cm
pelvic width	less than 39cm
external dimensions	length (depth) 292mm x width 450mm x height 522mm
weight	3.1kg (including a battery)
range of joint motion	Hip joint : Extension 30°/ flexion 130°
operating environment	temperature : 0℃~40℃ humidity : 20%~80% * (no condensation)
ingress protection rating	IP54
drive time	ca. 4.5 hours

PRODUCT 8: INNOPHYS – Muscle Suit

https://innophys.jp/en/product/power/

Figure 0-8 https://innophys.jp/en/product/power/

The Muscle Suit is the creation of Innophys and it is part of a broad effort in East Asia to create wearable devices to assist the workers of an aging population.

The Muscle Suit is a powered hip exoskeleton for lifting (pick and carry). It uses compressed air that is stored in a high-pressure cylinder attached to the back. Alternatively, the suit can be connected to a compressed air hose, commonly found in many worksites. It can also be powered using a portable compressor, but they can be loud.

Controlling the Muscle Suit can be done in one of two rather unique ways. The user can either touch a control surface using their chin or blow into a tube. This creates a hands-free control system for a powered exoskeleton.

The muscle suit is wrapped inside a custom, water repellent bag. This protects the device from the elements and gives it a softer appearance.

There are three different versions of the Muscle Suit depending on the amount of power that is needed for the application. The device weighs anywhere from 4.5 to 5.5 kg (10 to 12lb).

Specifications

Size	Small/medium size, medium/large size
Product dimensions: Height × Width × Depth	Small/medium size: 810 mm × 450 mm × 200 mm (31.9" × 17.7" × 7.9") Medium/large size: 900 mm × 500 mm × 220 mm (35.4" × 19.7" × 8.7")
Product weight	6.6 kg (14.6 lb) (*1)
Driving force	Compressed air
Actuator	McKibben artificial muscle × 4
Method of supplying compressed air	External supply using a compressor (*2) / Manual pump
Assistive force	Up to 35.7 kgf (140 Nm) = 78.7 lbf (103 ft-lb)
Area of assistance	Back
Environmental temperature during use	5°C～35°C
Applicable body height (recommendations)	Small/medium size: 150 cm to 165 cm (4" 11' to 5" 9') Medium/large size: 160 cm to 185 cm (5" 3' to 6")
Water-resistant cover	Not included
Interface	Air intake switch (*3)
Sound level	Under 70 dBA (*4)
Manufacturer's warranty period	Two years (One free inspection) (*5)

(*1) Excluding cover.

(*2) The product functions at 0.5 MPa (72.5 psi), but 0.8 MPa (116.0 psi) is recommended to achieve smooth operation.
A mobile battery is needed to power an electric valve that controls the flow from the external air supply.

(*3) Only when using a compressor.

(*4) When running on a compressor.

(*5) Warranties of up to four years are available as paid options.

Pacer: The Power of Mobility

Product 9: INDEGO – Indego Therapy

http://www.indego.com/indego/en/Indego-Therapy

Indego Therapy is a lower limb powered exoskeleton which enables therapists to offer task specific and intensive gait training. Sophisticated motors in the knee and hip joints, combined with advanced sensors and control strategies, allow individuals with weakness or paralysis in their lower extremities to stand and walk again.

Indego is used in rehabilitation centers as a therapy tool to offer task-specific, over-ground gait training on a variety of surfaces. Indego allows for fast set up time and efficient therapy sessions. Indego Therapy also allows therapists to make sizing adjustments while the user is standing in the device. These features of Indego Therapy allow therapists to challenge their patients effectively, and to potentially achieve a more intense training session with less physical exertion on the part of the therapist.

Figure 0-9
http://www.indego.com/indego/
en/Indego-Therapy

Versatile Software Suites

Every Indego Therapy comes with Motion+ Software to treat patients with more severe or complete injuries and Therapy+ Software for patients with partial and mild impairments.

Modular Design

Indego can be donned and doffed quickly because of its five-component design, self-aligning connections, and single hand adjustment system.

Lightweight

At just 39 lb (17.7 kg), Indego Therapy is light, easy to handle, and allows for rapid set up, and easy transportion. It has no backpack or upper body components and can be worn while seated in a standard wheelchair.

Indego App

Indego's iOS app allows real time control over gait training parameters such as stride length, step frequency, and step height. It also records walking data so therapists can easily quantify results.

Technical Data

Power	Rechargeable Li-ion battery provides a day of clinical use
Maximum	Assembled device: 39 lb (17.7 kg)
Sizes	• Hip width range: 13.3" - 16.6" (34 - 42.2 cm) • Upper leg length range: 14.6" - 19.3" (37 - 49 cm) • Lower leg length range: 16.5" - 21.7" (42 - 55 cm)
Interface	• User feedback provided by vibration and color changing LEDs • View and modify device settings via Indego app over Bluetooth connection
Patient Requirements*	Height range: 5'1" – 6'3" (155 – 191 cm) Maximum weight: 250 lb (113 kg) Maximum hip width: 16.6" (42.2 cm) Femur length: 14" – 18.5" (35 – 47 cm)

	Spasticity score: Modified Ashworth score 3 or lower Sufficient upper body strength to balance and advance with forearm crutches, front-wheeled walker or platform walker For complete and incomplete spinal cord injured individuals C7 or below and individuals with hemiplegia (with motor function of 4/5 in at least one upper extremity) due to cerebrovascular accident (CVA) in the U.S. For individuals with lower limb weakness or paralysis in Europe
Operating Conditions	• Temperature range: 32° – 104°F (0° – 40° Celsius) • Relative humidity: 30% – 75%
Indego Therapy Includes	• Adjustable hip unit with air-foam chambers for customizable fit • One pair of adjustable upper legs • Three pairs of adjustable lower legs (sized small/medium/large) • Indego app on Apple iPod Touch/handheld controller • Quick adjustment tool • Stability aids (rolling walker with platform attachment and forearm crutches

Product 10: SKI-MOJO – Skimojo Gold

https://www.skimojo.com/product/ski-mojo-gold/?v=3e8d115eb4b3

Figure 0-10
https://www.skimojo.com/product/ski-mojo-gold/?v=3e8d115eb4b3

The Ski~Mojo is a passive knee exoskeleton for skiing. It is a spring dampener for the knees, much like a shock absorber system in a car. The design leverages the fact that skiers have to wear rigid boots by attaching the exoskeleton to them.

The Ski~Mojo can be worn over or under clothing. The device greatly reduces the physical impact from bumps and shocks on the body. It significantly delays muscle fatigue and reduces pain in the legs (theoretically, it should also reduce pain in the lower back). The exoskeleton is engineered to remove up to 1/3 of the strain in the knees while skiing.

This patented ski~mojo product is precision engineered from the highest quality materials and is fully adjustable to ensure a great fit whatever your size.

The only choice you have to make is to choose the appropriate strength of springs for your weight:

The Gold ski~mojo is suitable for skiers weighing more than 75Kg;

The Silver ski-mojo is suitable for skiers weighing up to 85Kg.

For skiers weighing between 75Kg and 85Kg either model is suitable.

Suitable for skiers weighing between 75Kg & 125Kg (165lbs or 11stone 11lbs to 275lbs or 19stone 9lbs) and over…

Skiers weighing more than this can still use the Gold ski~mojo, they will receive less support as a % of their weight

Comes complete with everything you need.

When buying direct online you are protected by statutory 'Distance Purchasing' rights – you can return the item within 7 days of receipt (in an unused condition) for a full refund.

As the manufacturer, we always sell the most up-to date specification and orders to mainland UK are shipped free of charge by next working day courier.

When buying direct your Warranty is automatically registered.

Product 11: RB3D – Hercules

https://www.rb3d.com/en/exoskeletons/exo/

RB3D is specialized in strength assistance. Initiated by French DGA (Direction générale de l'armement) with their RAPID program, RB3D started to develop HERCULE in 2009. Its development was made in partnership with CEA List and ESME SUDRIA., HERCULE was exhibited in several occasions : at MILIPOL Fair in october 2011, and EUROSATORY in june 2012.

Following the first evaluations, DGA encouraged new developments both for civilian and military applications. In parallel with a second RAPID program from DGA, RB3D started the project to develop a Civilian exoskeleton for to carry and manipulate loads and tools. This new project got the attention of additionnal financial partners who provided us significant ressources to allow the design of HERCULE V3 in 2013.

Figure 0-11
https://www.rb3d.com/en/exoske
letons/exo/

HERCULE V3, Mobile strength assistance.

This 3rd version of HERCULE is dedicated to civilian applications. It has been thought as a development platform for industrial applications, upon which will come various kind of arms or accessories to fit with and fulfill the needs of the numerous industrial cases we target.

As an open software version, HERCULE can adress as well R&D labs that look upon to make reasearch activities on exoskeletons and control/command programs.

Decisive Advantages

HERCULE V3 is designed to fit easily with a wide variety of body sizes. It has quick links which allow to dress or undress with the exoskeleton in less than a minute. An ergonomic HMI helps to select 2 modes for a simple use :

– Dress/Undress is the mode which is used to fit the equipement.

– Action is the active mode which allows to start with strength assistance for all applications.

Equipped with the latest generation of electrical cable actuators, HERCULE provides exceptionally smooth running and high energy efficiency. Autonomy is thus reinforced and allows to run at least 4 hours in nominal use.

HERCULE V3 has a computer heart ARM Cortex-A8, for a real-time movement management.

HERCULE V3 allows most trips: walk flat or on slopes up to 10 °, climb stairs, get into squatting or sitting position.

Technical features

Weight	30 kg
Power (peak)	600 W
Battery	Li-Ion rechargeable.
Dimensions	Height : 1100 mm (Taille L) – Width : 650 mm – Depth : 400 mm
Architecture	14 degrees of freedom amongst which 4 motorized
Links with user	Dorsal Harness, shoe straps

SIZE /WEIGTH	BETWEEN 60 AND 100 KG
Between 1,66 and 1,73 m	M
Between 1,73 and 1,78 m	L
Between 1,78 and 1,88 m	XL

Appendix III: Product Research

Objectives

- To review comparable products in the marketplace
- To determine the features and benefits for the products
- To assess competitor benefits to help define possible design niches
- To draw conclusions that will ‘inform design’

Thesis Topic

The topic for this thesis is mobility of amputees.

Section 1. Benchmarking I – Generating a Table Comparing Main Features

Method

Promotional media (literature/internet) of competitor products are researched and evaluated to determine features and benefits, and their relative importance to design of a new product. In some cases, products were selected on the basis that they had met similar user needs as the thesis topic, but may have differed substantially on other needs.

Competitors

The following is a list of products that are similar in user and or function, they range from powered to non-powered in a variety of materials, range of motion, size, and function. These competitors will serve as a basis for understanding the potential and current competition to this thesis project outcome.

Table 1.

Product Benchmark List			
1	EKSO Bionics – Ekso Vest	7	Cyberdyne – HAL Lumbar Type for Well
2	SUITX – BackX	8	INNOPHYS – Muscle Suit
3	SUITX – LegX	9	INDEGO – Indego Therapy
4	SUITX – ShoulderX	10	SKI-MOJO – Skimojo Gold
5	SUITX – PHOENIX Medical Exoskeleton	11	RB3D – Hercules
6	Cyberdyne – Lower Limb Type	12	---

Evidence

A Table comparing the main features for 8 of the 11 comparable products was constructed. The main features chosen for comparison were:

- User Weight Max
- Driving Force (motorized/battery)
- User Height Range
- Assistive Force
- Water Resistance
- Operating Time
- Links with User
- Materials

- Unit Weight

Feature Comparison Table

								
Max User Weight	N/A	N/A	N/A	40kg~100kg	40 – 80kg	N/A	250 lb (113 kg)	60 - 100kg
Driving Force	Non-Powered	Non-Powered	Motorized/ Battery	Motorized/ Battery	Motorized/ Battery	Compressed Air	Motorized/ Battery	Motorized/ Battery
User Height Range	5’0” – 6’4” (152 – 193 cm)	height and waist sizes (5%-95% of human dimensions)	Variable	150 - 200cm	140 - 180cm	*Small/medium* size: 150 cm to 165 cm (4" 11' to 5" 9') *Medium/large* size: 160 cm to 185 cm (5" 3' to 6")	5'1" – 6'3" (155 – 191 cm)	N/A
Assistive Force	5-15 LB. lift assist per arm	Reduces compression on the spine at L5/S1 disc by an average of 60%	speed of 1.1 miles/hour (0.5 m/sec), Vertical support	hip joint: extension 20˚/flexion 120˚ knee joint: extension 6˚/flexion 120˚	hip joint: extension 30˚/flexion 130˚	Back - Up to 35.7 kgf (140 Nm) = 78.7 lbf (103 ft-lb)	Vertical support	allows most trips: walk flat or on slopes up to 10 °, climb stairs, get into squatting or sitting position.
Water Resistance	Yes	Yes	Yes	No	Yes	Yes	yes	yes
Operating Time	Unlimited	Unlimited	4-8 hours	1 hour	4.5 hours	Dependent on use	2 hours	4 hours
Links with User	Waist, back, shoulders, arms	Waist, back, shoulders	Hip, back, shoulders, knees, Shins, Feet	Hip, back, shoulders, knees, Shins, Feet	Waist, Lumbar, Quads	Waist, back, shoulders, Quads	Hip, back, shoulders, knees, Shins, Feet	Hip, Feet
Materials	Nylon, Aluminum, Rubber	Nylon, Aluminum, Rubber	Nylon, Aluminum, Rubber, Polymer (high impact)	Nylon, Aluminum, Rubber, Polymer (high impact)	Nylon, Aluminum, Rubber, Polymer (high impact)	Nylon, Aluminum, Rubber, Polymer (high impact)	Nylon, Aluminum, Rubber, Polymer (high impact)	Nylon, Aluminum, Rubber, Polymer (high impact)
Unit Weight	9.5lb. (4,3kg)	4.9 lb (2.2 kg) and it is worn with an Exoskeleton Harness that	12.25kg (27 lbs)	14kg	3.1kg	4.5 to 6.6 kg (14.6 lb.)	39 lb (17.7 kg)	30kg

		weighs 2.5 lbs (1.1 kg)						

Table 2.

Table 3.

Design Elements Comparison Table								
								
Overall Form (categories below reflect type of product selected)								
Shape Geometric (Rectilinear, Ellipsoid, Cylindrical etc)	Cylindrical	N/A	Ellipsoid, Cylindrical	Ellipsoid, Cylindrical	Ellipsoid, Cylindrical	N/A	Ellipsoid, Cylindrical	Rectilinear
Repetition Arrays of holes Arrays of lines	Straps/ Supports	Straps	Braces, joints	Braces, joints	Braces,	Braces, Straps, Supports	Braces, joints	Braces, joints
Pattern	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Blue Stripe
Balance (symmetry etc))	Left mirrors Right	Left mirrors Right	Left mirrors Right	Left mirrors Right	Left mirrors Right	Left mirrors Right	Left mirrors Right	Left mirrors Right
Interface Comparison Table								
Buttons / Dials	N/A	N/A	N/A	Soft touch buttons	N/A	N/A	Buttons for Assisted walk	Power
Light indicators	N/A	N/A	N/A	Power/ Battery	N/A	N/A	Buttons light up	Power/ Battery
Touch interface	N/A	N/A	U/I	N/A	N/A	N/A	N/A	N/A
Other	N/A	N/A	N/A	LED screen	N/A	N/A	N/A	N/A

Promotional literature for these products is shown in appendix 1

Conclusion

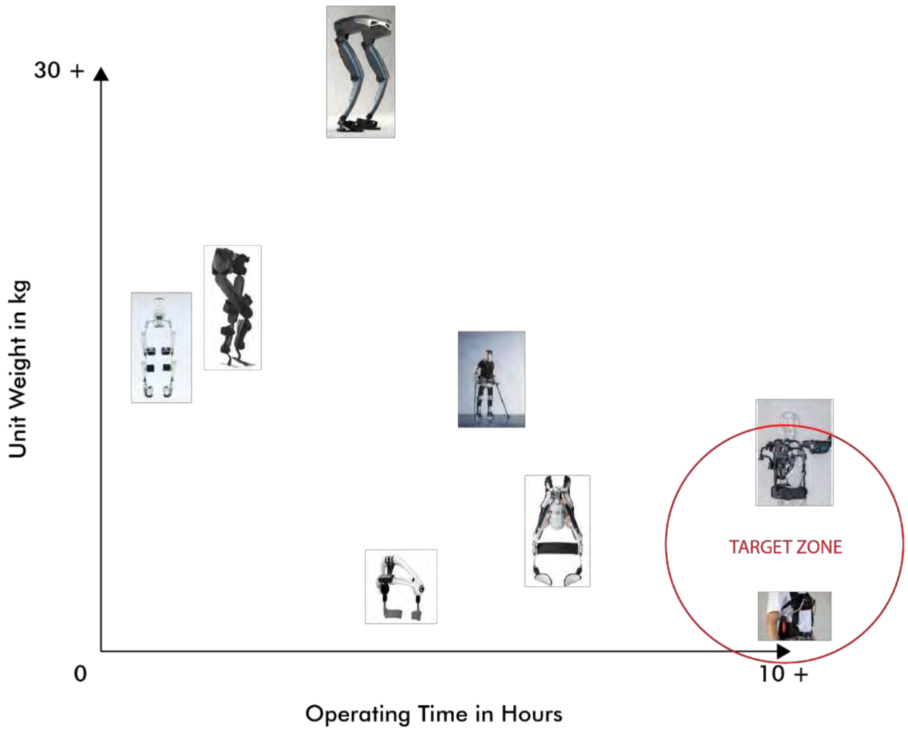
While the variety of products available is large, most products tend to be cumbersome or limited in modularity. Operating time is low depending on amount of use by user and type of technology implemented. Opportunities exist in making mobility products lighter, smaller, and being less obtrusive. Advancements in tech afford ability to make these products more accurate, modular, stronger, and hidden.

Section 2. Benchmarking II – Comparing Pairs of Features on an X-Y Graph

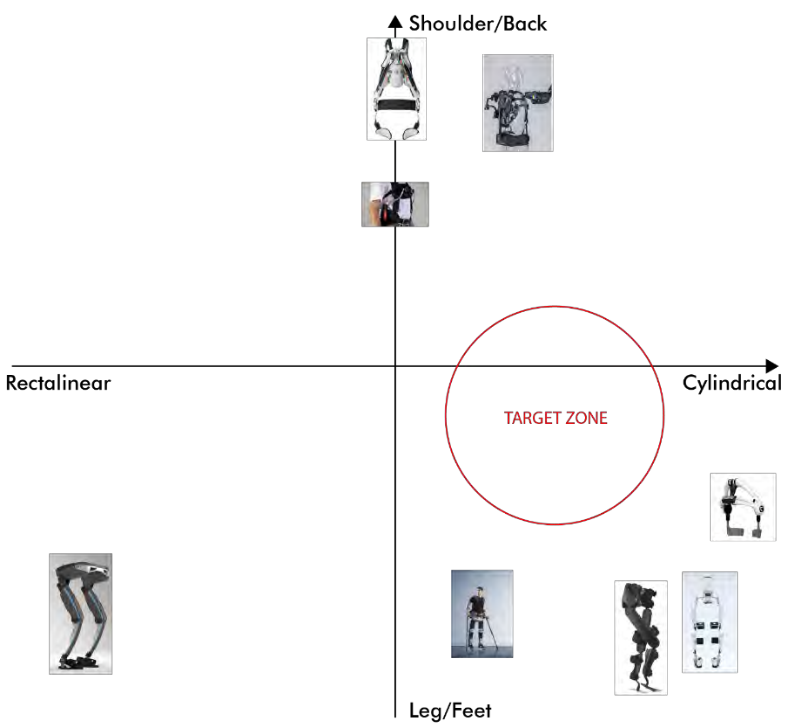
2.1 Method

Pairs of features were selected to create X-Y graphs. The paired features were assigned to either the X or Y axis, images of each of the comparable products placed on the graph. The intent is to see if patterns emerge which could indicate a zone of opportunity in the market. The first graph compares unit weight to operating time. These were chosen to see if there is any correlation between how heavy the mobility device is and how long they are able to operate for. The second graph compares elements of design and location of contact points. These were chosen to identify if the form is informing the location and or use of each device, and where there might be opportunities for design and market niches.

2.2 X-Y Graph 1



2.3 X-Y Graph 2



2.4 Conclusion

- Exoskeletons are a secluded and specialized market due to healthcare aspect and number of companies designing and producing these types of products.
- The first graph shows a pattern where the weight directly affects the operating time. The trick is to design an effective product that is light and has a long time of operation, while still integrating tech.
- Most current products lean towards designs that lend to organics and anthropometrics.
- Current design is clunky and cumbersome
- Products that concern leg support are generally bulky while upper body and more slim
- Opportunity in designing a product that is sleek for both upper and lower body.
- More opportunities may lie in power options and cost benchmarking.

Section 3. Benchmarking III – Determining Main Benefits and Features of Comparable Products

3.1 Methods

Determining the features and benefits for a product or related product is key to inform design and user needs. Using promotional material for all 11 products related to the thesis topic; where the frequency of descriptive words is compiled and recorded, then organized as the top 5 most common words used in those related products.

- **Benefits** are the hooks that catch the customers and makes them want a product over competing products. Benefits describe how a product will aid the user in performing tasks or making the product sound more exciting.

- **Features** are technical information/stats that inform the user of a products capabilities and or composition.

3.2 Key Benefits

Top 5 words associated with benefits, as determined from promotional materials. Listed as follows

Table 4.

Key Benefits of Comparable Products	
1	Comfort
2	Support
3	Reduction of Injury
4	Control/Function
5	Reduction of Forces

3.3 Key Features

Top 5 words associated with features, as determined from promotional materials. Listed as follows

Table 5.

Key Features of Comparable Products	
1	Weight
2	Adjustable
3	Power/Rechargeable
4	Assisted Force
5	Modular

Section 4. Summary/Discussion

4.1 Overall Feature Comparison

Two Products close to the ‘design opportunity’ on graph 1 were assessed and compared on how they met customer needs. The two products selected were:

3. EKSO Bionics – Ekso Vest
4. SUITX – BackX

4.2 Features Comparison

Results are seen in the table below. Benefits are identified for this product based on previous sections. Possible niche markets are deficits in current product offerings.

Table 6.

Features	Features Comparison		
	EKSO Bionics – Ekso Vest	SUITX – BackX	Possible Niche Market
Weight	Good	Great	
Adjustable	Good	Good	
Power/Rechargeable	Poor	Poor	X
Assisted Force	Fair	Poor	X
Modular	Poor	Fair	X

Section 5. Summary/Discussion

Pacer: The Power of Mobility

5.1 Key Benefits, Features

A side by side comparison of key benefits and features, as determined by promotional materials highlighted in the tables below.

Table 7.

Key Benefits of Comparable Products	
1	Comfort
2	Support
3	Reduction of Injury
4	Control/Function
5	Reduction of Forces

Key Features of Comparable Products	
1	Weight
2	Adjustable
3	Power/Rechargeable
4	Assisted Force
5	Modular

5.2 Updated Needs Statement

Design a lightweight, modular mobility device/product for amputees that will fit a wide range of body types, while improving the way they move through physical space. This Device should explore ways to improve comfort, support, safety, control, and reduction of forces.

Appendix:

PRODUCT 1: EKSO Bionics – Ekso Vest

Pacer: The Power of Mobility

https://eksobionics.com/eksoworks/eksovest/

Description - EksoVest is an upper body exoskeleton that elevates and supports a worker's arms to assist them with tasks ranging from chest height to overhead. It is lightweight and low profile, making it comfortable to wear in all conditions while enabling freedom of motion.

The Specific Worker (SW) EksoVest is one (1) device assembled with a single set of components to fit the measurements of an individual. This includes the base device along with: one pair of arm cuffs, one pair of upper arm straps, one hip belt, and one pair of springs. You must use our measurement guide in the Operator Manual to submit your component sizes when purchasing a Specific Worker Device. This kit has a lower price due to the fewer number of components included. We recommend purchasing these SW kits for individual operators after completing in-house trials with our GC kits that can be adjusted to fit different size workers.

Note: you can always purchase additional components for your SW EksoVest to adjust the fit for a different sized operator.

Figure 0-12 -
https://eksobionics.com/eksoworks/eksovest/

SPECIFICATIONS:

- 5-15 LB. lift assist per arm
  lift force can be adjusted to fit application and operator preference
- Reduced fatigue & increased endurance
  operators become less tired over the course of their shift leaving them with more energy at the end of the day
- Rugged design. Built with durable materials and tested to withstand wear & tear on the job
- Customizable size. Eksovest can be adjusted to provide a custom fit to a wide range of operator sizes
- Healthier workers
  lessening the strain on operators' shoulders and back reduces the likelihood of on the job injuries
- Improved worker morale reduction in fatigue and injury leads to happier workers and improved worker retention
- Unit weight: 9.5lb. (4,3kg)
- Worker height range: 5'0" – 6'4" (152 – 193 cm)

The General Configuration (GC) EksoVest is a full kit that includes all available components for one (1) device. This includes the base device along with: three pairs of arm cuffs (S, M & L), three pairs of upper arm straps (S, M & L), two hip belts (S/M & L/XL), the hip belt extender, and four pairs of springs (Levels 1, 2, 3 & 4) along with storage bags for the extra components when not in use. This kit has a higher price due to the additional components included. We recommend purchasing these GC kits first so you can try out EksoVest with multiple operators of different sizes for your application and then purchasing additional SW kits for individual operators as needed.

PRODUCT 2: SUITX – BackX

https://www.suitx.com/backx

backX is a novel industrial exoskeleton that substantially augments its wearer and reduces the forces and torques on a wearer's lower back region (L5/S1 disc) by an average of 60% while the wearer is stooping, lifting objects, bending or reaching. backX augments the wearer's strength and can reduce the risk of back injuries among workers. Designed for all-day wear, backX never impedes natural movements and the wearer can walk, ascend and descend stairs and ladders, drive automobiles, ride bicycles, run and perform any maneuver with absolutely no restriction.

Figure 0-13

https://www.suitx.com/backx

Features

- REDUCE BACK STRAIN: Reduces compression on the spine at L5/S1 disc by an average of 60%
- ZERO IMPEDANCE: Ascending and descending stairs and ladders, running, driving, and biking are completely unimpeded
- RUGGED: Designed to withstand harsh industrial environments, backX is WATERPROOF, DUSTPROOF, and easy to maintain
- NO BATTERIES: Cleverly designed to reduce the risk of back injuries without the use of batteries, actuators, or computers
- LOW PROFILE: Follows user's body to fit in tight spaces and changing environments
- COMFORTABLE: Good for all day use. Minimal inhibition of arm, leg, and torso range of motion
- QUICK DONNING AND DOFFING: backX can be put on and taken off in less than 30 seconds
- COMPATIBLE: Works with safety harnesses, tool belts, and can be worn under reflective vests and work jackets
- ADJUSTABLE SIZE: Fits a wide range of height and waist sizes (5%-95% of human dimensions)
- ADJUSTABLE SUPPORT: Support force can be quickly changed by the user to accommodate different tasks, and fatigue level
- OPTIMIZED SUPPORT: Support force is optimized based on bending angle. Does not impede non-bending tasks
- MODULAR: Can be worn with shoulderX and legX

MODEL S: Both models can be worn by itself. Model S is compatible with **legX**

- Model S hardware weighs 4.9 lb (2.2 kg) and it is worn with an Exoskeleton Harness that weighs 2.5 lbs (1.1 kg)
- Model S features a frame design that keeps the rear belt open and accessible when reaching for tools.

MODEL AC: Model AC is compatible with both legX and shoulderX

- Model AC hardware weighs 7.5 lb (3.4 kg) and it is worn with an Exoskeleton Harness that weighs 2.5 lbs (1.1 kg)
- Model AC frame is load-bearing: the Model AC will transfer the weight of attached loads directly to the hips (analagous to a backpack waistbelt) or to the ground if legX is attached.

PRODUCT 3: SUITX – LegX
https://www.suitx.com/legx

legX is a revolutionary knee exoskeleton that allows the wearer to squat repeatedly or for prolonged periods of time by reducing the knee joint and quadricep muscle forces. The amount of support can be adjusted to suit the needs and weight of the user. The legX is offered with a custom work boot to maximize user comfort. This intelligent system can distinguish between walking, ascending/descending stairs and squatting to allow unimpeded locomotion and only provides support when support is desired. legX also has a locking mode, where the exoskeleton can be used like a chair. An anthropomorphic profile and adjustable sizing allows for natural movement and intuitive awareness of one's position within tight spaces. legX moves freely with a worker without impeding the wearer while providing support during squatting tasks.

Figure 0-14 https://www.suitx.com/legx

Features

REDUCES KNEE FATIGUE AND FORCES: Substantially reduces effort of the knee muscles, thus reducing knee joint force.

INTELLIGENT: Can distinguish between walking, ascending/descending stairs and squatting to allow unimpeded locomotion and only provides support when support is needed.

ZERO IMPEDENCE: legX does not impede common day-to-day activities such as ascending and descending stairs, and even driving or biking. legX moves freely with a worker without impeding the wearer while providing support during squatting tasks.

COMFORTABLE: An anthropomorphic profile and adjustable sizing allows for natural movement and intuitive awareness of one's position within tight spaces.

WORKS WITH EXISTING GEAR: legX can be used with tool belts and safety harnesses allowing standard worker equipment to retain its existing functionality.

COMPATIBLE: legX can be used in combination with backX to provide additional support and is part of the entire MAX system when combined with the backX and shoulderX.

ADJUSTABLE SUPPORT FOR THE USER: The amount of support can be adjusted to suit the needs and weight of the user.

LIGHTWEIGHT: Pair of legs weigh 13.7 lbs (6.2 kg). The weight of the device is not borne by the user.

ADJUSTABLE SIZE: legX is adjustable to various sizes and can be worn all day.

Numerous uses of legX at various sites

Workers in jobs with a high risk of knee injury share common experiences; they all perform repetitive squatting or endure prolonged periods of time in a squatting posture. legX is designed based on solid engineering foundations at the University of California, Berkeley and suitX with close attention to workers' needs and feedback.   legX have been used in numerous industrial applications as shown below.

PRODUCT 4: SUITX – ShoulderX
https://www.suitx.com/shoulderx

Figure 0-15
https://www.suitx.com/shoulderx

shoulderX V3 is the world's most advanced shoulder-supporting exoskeleton for use by automotive, construction and shipbuilding workers. shoulderX augments its wearer by reducing forces at the shoulder complex, substantially reducing the risk of shoulder injuries and increasing workplace productivity.

The third-generation industrial exoskeleton incorporates novel features based on the feedback obtained from numerous field evaluations across the globe. shoulderX V3 introduces a novel human interface technology that can automatically conform to each user's unique body shape to achieve an impeccable fit and unparalleled comfort. This interface provides a firm fit to the user, reducing slippage (sagging) between the wearer and the exoskeleton and, hence, reducing the need to perform micro-adjustments of the device during use, as commonly observed in other devices. Additionally, this interface provides superior breathability and has an exceptional ability to remove heat from the user, thereby maximizing user comfort. shoulderX V3 reduces the inventory a customer must manage to support their workforce by providing these key features: First, it is fully adjustable making it a "one-size-fits-all" wearable exoskeleton, resulting in a single unit addressing the needs of users of various shapes and strengths; second, this novel exoskeleton provides a wide range of strength output through a tool-less adjustment mechanism and it does not require multiple cartridges or gas springs. The third generation of shoulder-supporting exoskeleton boasts a 40 percent reduction in weight by use of carbon fiber without losing any of its industry-leading characteristics and range of support strength. Like its predecessor, the new design does not use electric power, does not need batteries, is available in multiple configurations such as fire retardant, dust-proof and water-resistant and is specifically designed to withstand extremely harsh environments such as construction sites and shipbuilding facilities.

Features and Benefits

- ADJUSTABLE SUPPORT: Support capacity can be quickly changed to accommodate different users, tools, tasks, and fatigue level.
- OPTIMIZED SUPPORT: Support force gradually increases as the user lifts his arms and becomes near zero when the arms are lowered, allowing the user to rest arms naturally or reach for tools on their tool belt.
- ADJUSTABLE SIZE: Fits range of worker height, waist size, shoulder width, chest depth, and arm length (5%-95% of human dimensions)
- ANTHROPOMETRIC PROFILE: Follows user's body to fit in tight spaces and changing environments
- LIGHTWEIGHT: shoulderX weighs 7 lbs (3.17 kg)
- BATTERIES NOT REQUIRED: Cleverly designed to reduce the risk of shoulder and arm injuries without the use of actuators and computers
- RUGGED: Waterproof, dustproof, and easy to maintain
- COMFORTABLE: Minimal inhibition of arm and torso range of motion. Designed for all-day wear
- MODULAR: One or two arm use, compatible with legX.

Pacer: The Power of Mobility

- COMPATIBLE: Compatible with tool belts, allowing workers normal equipment to retain functionality
- **Quick Donning and Doffing:** Less than 1 minute to put on or take off

Competitive Edge

- Unlike other devices in the market, shoulderX does not require additional hardware (cartridges, cassettes, springs, etc.) to adjust shoulder support strength. This eliminates the risk of losing components and eliminates the need to coordinate and carry additional components.
- Unlike other devices that protrude significantly behind its user, shoulderX has a slim profile that allows it to be used in confined spaces and reduce the risk of bumping into surrounding objects or personnel.

PRODUCT 5: SUITX – PHOENIX Medical Exoskeleton
https://www.suitx.com/phoenix-medical-exoskeleton

Figure 0-16 https://www.suitx.com/phoenix-medical-exoskeleton

The PHOENIX Medical Exoskeleton is the world's lightest and most advanced exoskeleton designed to help people with mobility disorders to be upright and mobile. In the clinic, at home, and in the workplace Phoenix has successfully enabled many individuals to stand up, walk about, and speak to peers eye-to-eye. Phoenix has only two actuators at its hip; the knee joints are designed to allow support during stance and ground clearance during swing. Phoenix is considered an investigational device and currently not available in the United States.

Major Features of PHOENIX:

- A modular exoskeleton allowing the user to independently put on and remove each piece.
- Weighs only 12.25kg (27 lbs), affording greater agility.
- A speed of 1.1 miles/hour (0.5 m/sec) has been clocked by a Phoenix user. However, the maximum speed depends on the individual user.
- On a single charge, Phoenix can walk for 4 hours continuously or 8 hours intermittently.

Pacer: The Power of Mobility

- Phoenix is adjustable for different size users and can be easily configured to fit individual conditions.
- An intuitive interface makes it easy for users to control standing up, sitting down and walking.
- Phoenix can comfortably be worn while seated in a wheelchair.

PRODUCT 6: Cyberdyne – Lower Limb Type
https://www.cyberdyne.jp/english/products/fl05.html

Cyborg-type robot fulfills wearer's will to stand and walk.

HAL for Well-Being Lower Limb Type Pro is a wearable robot designed for inducing the improvement of the physical function in the lower limb, for the wearer in chronic stages. Various upgrades were applied to this device, compared to its previous model, HAL for Well-Being Lower Limb Type.

Figure 0-17 https://www.cyberdyne.jp/english/products/fl05.html

SPECS and FEATURES

External dimension	length 430mm x width 470mm x height 1,230mm *1
Weight	Double-leg model/approximately 14kg *2 Single-leg model/approximately 9kg *2
Movable range	hip joint: extension 20˚/flexion 120˚ knee joint: extension 6˚/flexion 120˚
Weight limit	40kg~100kg
Operating time	approximately 1 hour

※3

Power source custom battery

*1

Dimension of S size unit, on the shortest setting

*2

Includes cuffs, sensor shoes and batteries

*3

May differ subject to operating environments and conditions

*

The product is designed for the wearer who requires support due to difficulties standing, sitting and walking. As the device uses bio-electrical signal to support the movement, if bio-elecrical signal cannot be detected, the device will not support the wearer with the intended movement. In this case, the wearer may not use the device.

<table>
<tr><th>Size</th><th>S Size</th><th>M Size</th><th>L Size</th><th>X Size</th></tr>
<tr><td>Height [approximately]</td><td>150~165cm</td><td>160~175cm</td><td>170~190cm</td><td>180~200cm</td></tr>
<tr><td>Upper leg length</td><td>36~38cm</td><td>38~41cm</td><td>40~45cm</td><td>43~48cm</td></tr>
<tr><td>Lower leg length</td><td>35~38cm</td><td>37~41cm</td><td>39~45cm</td><td>42~48cm</td></tr>
<tr><td rowspan="2">Hip width</td><td colspan="2">M Size</td><td colspan="2">W Size</td></tr>
<tr><td colspan="2">28~36cm</td><td colspan="2">32~40cm</td></tr>
<tr><td>Shoe Size</td><td colspan="4">23.0, 24.0, 25.0, 26.0, 27.0, 28.0, 29.0, 30.0 cm</td></tr>
</table>

PRODUCT 7: Cyberdyne – HAL Lumbar Type for Well Beinghttps://www.cyberdyne.jp/english/products/bb04.html

Figure 0-18 Beinghttps://www.cyberdyne.jp/english/products/bb04.html

New HAL for realizing Zero Burdening-care Society

HAL Lumbar Type Well-being (BB04) is a Wearable Cyborg that could be applied for two roles. The device supports both caregiver and care-receivers. When it's used by "caregiver" it reduces the stress applied on the lumbar region during care movement and reduces the risk of back injury. When it's used by "care-receivers", it could help a person with weak legs to maintain and improve his/her body function.

Reduction of physical burden of caregivers leads to improvement of labor environment and prevention of work accident. Additionally, enhancement of independence of care-receiver, such as sit to stand action without support reduces burden of the person himself/herself, but also significantly reduce the burden of caregiver. Double role of new HAL will approach solving the issues of aging society in two-ways, leading to realization of Zero Burdening-care Society.

applicable range of height (approximate)	140 ~ 180cm
applicable range of weight (approximate)	40 ~ 80kg
abdominal girth	less than 120cm
pelvic width	less than 39cm
external dimensions	length (depth) 292mm x width 450mm x height 522mm
weight	3.1kg (including a battery)
range of joint motion	Hip joint : Extension 30°/ flexion 130°
operating environment	temperature : 0℃~40℃ humidity : 20%~80% * (no condensation)
ingress protection rating	IP54
drive time	ca. 4.5 hours

PRODUCT 8: INNOPHYS – Muscle Suit

https://innophys.jp/en/product/power/

Figure 0-19 https://innophys.jp/en/product/power/

The Muscle Suit is the creation of Innophys and it is part of a broad effort in East Asia to create wearable devices to assist the workers of an aging population.

The Muscle Suit is a powered hip exoskeleton for lifting (pick and carry). It uses compressed air that is stored in a high-pressure cylinder attached to the back. Alternatively, the suit can be connected to a compressed air hose, commonly found in many worksites. It can also be powered using a portable compressor, but they can be loud.

Controlling the Muscle Suit can be done in one of two rather unique ways. The user can either touch a control surface using their chin or blow into a tube. This creates a hands-free control system for a powered exoskeleton.

The muscle suit is wrapped inside a custom, water repellent bag. This protects the device from the elements and gives it a softer appearance.

There are three different versions of the Muscle Suit depending on the amount of power that is needed for the application. The device weighs anywhere from 4.5 to 5.5 kg (10 to 12lb).

Specifications

Size	Small/medium size, medium/large size
Product dimensions: Height × Width × Depth	Small/medium size: 810 mm × 450 mm × 200 mm (31.9" × 17.7" × 7.9") Medium/large size: 900 mm × 500 mm × 220 mm (35.4" × 19.7" × 8.7")
Product weight	6.6 kg (14.6 lb) (*1)
Driving force	Compressed air
Actuator	McKibben artificial muscle × 4
Method of supplying compressed air	External supply using a compressor (*2) / Manual pump
Assistive force	Up to 35.7 kgf (140 Nm) = 78.7 lbf (103 ft-lb)
Area of assistance	Back
Environmental temperature during use	5°C～35°C
Applicable body height (recommendations)	Small/medium size: 150 cm to 165 cm (4" 11' to 5" 9') Medium/large size: 160 cm to 185 cm (5" 3' to 6")
Water-resistant cover	Not included
Interface	Air intake switch (*3)
Sound level	Under 70 dBA (*4)
Manufacturer's warranty period	Two years (One free inspection) (*5)

(*1) Excluding cover.

(*2) The product functions at 0.5 MPa (72.5 psi), but 0.8 MPa (116.0 psi) is recommended to achieve smooth operation.
A mobile battery is needed to power an electric valve that controls the flow from the external air supply.

(*3) Only when using a compressor.

(*4) When running on a compressor.

(*5) Warranties of up to four years are available as paid options.

Product 9: INDEGO – Indego Therapy
http://www.indego.com/indego/en/Indego-Therapy

Indego Therapy is a lower limb powered exoskeleton which enables therapists to offer task specific and intensive gait training. Sophisticated motors in the knee and hip joints, combined with advanced sensors and control strategies, allow individuals with weakness or paralysis in their lower extremities to stand and walk again.

Indego is used in rehabilitation centers as a therapy tool to offer task-specific, over-ground gait training on a variety of surfaces. Indego allows for fast set up time and efficient therapy sessions. Indego Therapy also allows therapists to make sizing adjustments while the user is standing in the device. These features of Indego Therapy allow therapists to challenge their patients effectively, and to potentially achieve a more intense training session with less physical exertion on the part of the therapist.

Figure 0-20 http://www.indego.com/indego/en/Indego-Therapy

Versatile Software Suites
Every Indego Therapy comes with Motion+ Software to treat patients with more severe or complete injuries and Therapy+ Software for patients with partial and mild impairments.

Modular Design
Indego can be donned and doffed quickly because of its five-component design, self-aligning connections, and single hand adjustment system.

Lightweight
At just 39 lb (17.7 kg), Indego Therapy is light, easy to handle, and allows for rapid set up, and easy transportion. It has no backpack or upper body components and can be worn while seated in a standard wheelchair.

Indego App
Indego's iOS app allows real time control over gait training parameters such as stride length, step frequency, and step height. It also records walking data so therapists can easily quantify results.

Technical Data

Power	Rechargeable Li-ion battery provides a day of clinical use
Maximum	Assembled device: 39 lb (17.7 kg)
Sizes	• Hip width range: 13.3" - 16.6" (34 - 42.2 cm) • Upper leg length range: 14.6" - 19.3" (37 - 49 cm) • Lower leg length range: 16.5" - 21.7" (42 - 55 cm)
Interface	• User feedback provided by vibration and color changing LEDs

Pacer: The Power of Mobility

• View and modify device settings via Indego app over Bluetooth connection

Patient Requirements*

Height range: 5'1" – 6'3" (155 – 191 cm)
Maximum weight: 250 lb (113 kg)
Maximum hip width: 16.6" (42.2 cm)
Femur length: 14" – 18.5" (35 – 47 cm)
Spasticity score: Modified Ashworth score 3 or lower
Sufficient upper body strength to balance and advance with forearm crutches, front-wheeled walker or platform walker
For complete and incomplete spinal cord injured individuals C7 or below and individuals with hemiplegia (with motor function of 4/5 in at least one upper extremity) due to cerebrovascular accident (CVA) in the U.S.
For individuals with lower limb weakness or paralysis in Europe

Operating Conditions

• Temperature range: 32° – 104°F (0° – 40° Celsius)

• Relative humidity: 30% – 75%

Indego Therapy Includes

• Adjustable hip unit with air-foam chambers for customizable fit

• One pair of adjustable upper legs

• Three pairs of adjustable lower legs (sized small/medium/large)

• Indego app on Apple iPod Touch/handheld controller

• Quick adjustment tool

• Stability aids (rolling walker with platform attachment and forearm crutches

Product 10: SKI-MOJO – Skimojo Gold
https://www.skimojo.com/product/ski-mojo-gold/?v=3e8d115eb4b3

Figure 0-21 https://www.skimojo.com/product/ski-mojo-gold/?v=3e8d115eb4b3

The Ski~Mojo is a passive knee exoskeleton for skiing. It is a spring dampener for the knees, much like a shock absorber system in a car. The design leverages the fact that skiers have to wear rigid boots by attaching the exoskeleton to them.

The Ski~Mojo can be worn over or under clothing. The device greatly reduces the physical impact from bumps and shocks on the body. It significantly delays muscle fatigue and reduces pain in the legs (theoretically, it should also reduce pain in the lower back). The exoskeleton is engineered to remove up to 1/3 of the strain in the knees while skiing.

This patented ski~mojo product is precision engineered from the highest quality materials and is fully adjustable to ensure a great fit whatever your size.
The only choice you have to make is to choose the appropriate strength of springs for your weight:
The Gold ski~mojo is suitable for skiers weighing more than 75Kg;
The Silver ski-mojo is suitable for skiers weighing up to 85Kg.
For skiers weighing between 75Kg and 85Kg either model is suitable.

Suitable for skiers weighing between 75Kg & 125Kg (165lbs or 11stone 11lbs to 275lbs or 19stone 9lbs) and over…
Skiers weighing more than this can still use the Gold ski~mojo, they will receive less support as a % of their weight
Comes complete with everything you need.
When buying direct online you are protected by statutory ‘Distance Purchasing’ rights – you can return the item within 7 days of receipt (in an unused condition) for a full refund.
As the manufacturer, we always sell the most up-to date specification and orders to mainland UK are shipped free of charge by next working day courier.
When buying direct your Warranty is automatically registered.

Product 11: RB3D – Hercules
https://www.rb3d.com/en/exoskeletons/exo/

RB3D is specialized in strength assistance. Initiated by French DGA (Direction générale de l'armement) with their RAPID program, RB3D started to develop HERCULE in 2009. Its development was made in partnership with CEA List and ESME SUDRIA., HERCULE was exhibited in several occasions : at MILIPOL Fair in october 2011, and EUROSATORY in june 2012.

Following the first evaluations, DGA encouraged new developments both for civilian and military applications. In parallel with a second RAPID program from DGA, RB3D started the project to develop a Civilian exoskeleton for to carry and manipulate loads and tools. This new project got the attention of additionnal financial partners who provided us significant ressources to allow the design of HERCULE V3 in 2013.

Figure 0-22 https://www.rb3d.com/en/exoskeletons/exo/

HERCULE V3, Mobile strength assistance.

This 3rd version of HERCULE is dedicated to civilian applications. It has been thought as a development platform for industrial applications, upon which will come various kind of arms or accessories to fit with and fulfill the needs of the numerous industrial cases we target.
As an open software version, HERCULE can adress as well R&D labs that look upon to make reasearch activities on exoskeletons and control/command programs.

Decisive Advantages

- HERCULE V3 is designed to fit easily with a wide variety of body sizes. It has quick links which allow to dress or undress with the exoskeleton in less than a minute. An ergonomic HMI helps to select 2 modes for a simple use :
  – Dress/Undress is the mode which is used to fit the equipement.
  – Action is the active mode which allows to start with strength assistance for all applications.
- Equipped with the latest generation of electrical cable actuators, HERCULE provides exceptionally smooth running and high energy efficiency. Autonomy is thus reinforced and allows to run at least 4 hours in nominal use.
- HERCULE V3 has a computer heart ARM Cortex-A8, for a real-time movement management.
- HERCULE V3 allows most trips: walk flat or on slopes up to 10 °, climb stairs, get into squatting or sitting position.

Technical features

Weight	30 kg
Power (peak)	600 W
Battery	Li-Ion rechargeable.
Dimensions	Height : 1100 mm (Taille L) – Width : 650 mm – Depth : 400 mm
Architecture	14 degrees of freedom amongst which 4 motorized
Links with user	Dorsal Harness, shoe straps

SIZE /WEIGTH	BETWEEN 60 AND 100 KG
Between 1,66 and 1,73 m	M
Between 1,73 and 1,78 m	L
Between 1,78 and 1,88 m	XL

Appendix IV: Bill of Materials

Bill of materials

Part/Feature/description	***Material***	***Manufacturing Method***
Pack connector	polymer	molding
Lower spine	Various/polymer	molding
Mid spine	Various/polymer	Molding
Upper spine	Various/polymer	Molding
Spine support pads left	Polymer	Molding
Spine support pads center	Polymer	Molding
Spine support pads right	Polymer	Molding
Lumbar support	Various	Sources
Cervical support	Various	Sourced
Vest to spine connector	Various	Sourced
Vest	Various	Sourced
Vest breast pad	Various	Sourced
Pack assembly	Various	Sourced
Pack pad – lumbar	Polymer	Molding
Pack pad - hip – left	Polymer	Molding
Pack pad – hip – right	Polymer	Molding
Femoral hip structure	Calcium phosphate	Molding
Knee cap	Calcium phosphate	Molding
Leg structure/cover	Calcium phosphate	Molding
Joint assembly	Various	Molding
Joint nut	Aluminum	Molding
Tib/fib assembly	Aluminum	Molding
Socket	Various	Molding/fabrication
Socket liner/pad	Various	Molding/fabrication
Motor/suspension housing	Various	Sourced
Heel pad	Polymer	Molding
Foot pad	Polymer	Molding
Toe pad	Polymer	Molding
Foot body	Various	Molding/sourced
Toe body	Various	Molding/sourced

Appendix V: Sustainability Report

Abstract

A sustainable mobility aid in the health care and long-term use of amputees' sector is important. The products have to be able to not only comfortable to the user, but also durable enough to withstand day to day use for extended periods of time. Prostheses, walkers, canes, and even exoskeletons as we move into the future are valuable tools in the mobility of those who have suffered from lower limb loss. This report looks at materials and manufacturing behind current mobility aids as well as sustainability efforts, user health and safety, and environmental initiatives seen in benchmarked products. Lastly the report discusses design features of the final design for this mobility aid thesis proposal.

Introduction

Due to the nature of their use, and the need for them to be reliable, mobility aids for amputees must maintain working order and be durable enough to withstand everyday use for upwards of 13 hours a day. The mobility of the user depends directly on the mobility aid, if it were to fail during use it could mean that the user sustains a fall/injury and could be left in a prolonged state of hindered mobility. The devices durability then hinges directly on the ability maintain working order. Currently mobility aids such as prostheses', walkers, canes/crutches utilize lightweight materials that are strong enough to support the weight of the user but afford strength and durability. The interactions and the spaces that the users will expose these devices to vary, from urban city centers to rural neighborhoods, and even natural environments such as national parks. The extended use of these devices, some being upwards of 13 hours, for a plethora of reasons; indicates that the materials must be selected to reflect their use, furthermore the health and safety of the user are the most important factor when considering the design features for the final mobility aid thesis proposal. By looking at current and future directions of sustainability related to health, user safety, and the environment; information can be gathered for the purpose of creating and deciding a feasible design direction and features for the mobility aid.

Literature Review

Reporting on sustainability for mobility aids in regards to lower-limb amputations requires an in depth look at sources on the topic of sustainability. This report looks at current and potential technologies being implemented in the field of mobility and balance for those with lower-limb amputations and mobility disfunctions. The article, *Review of nanocellulose for sustainable future materials,* discusses the manufacture and implementation of nanocellulose in the reinforcement of thermosetting plastics and medical sectors for hygiene and absorption products. Nanocellulose also has the unique quality of being able to successfully integrate with smart technology allowing it to synthesize with the proposed mobility aid in order to help create haptic feedback to the residual limb and spine during stretch reflex.

This report will also touch on the health and safety of the users. Reflecting on articles and reports found on this topic will help the discussion and analysis of these concerns. Two articles *Growth and Advancements in Neural Control of Limb* and *What Are Some of the Long-Term Physical Effects of Using or Not Using a Prosthesis.* These articles give an overview of the negative long- and short-term health effects of living with a lower limb amputation and the possibility of and possible effects of introducing neural control to prosthetics. The introduction of some form of neural control has the potential to not only alleviate some of the negative health concerns, but also reintroduce the haptic information that has been lost due to amputation including stretch reflex and the subtle balance controls in the ankle, knee, and hips. Another article to supplement the effects of balance control, health and limb loss was used, the article named *Human balance and posture control during standing and walking* helped develop an understanding of the users' needs and potential effects of loss of balance control. These articles were used to help enhance the understanding of the topic and provide evidence for their need in order to help provide a clearer final design solution (US6537589B1).

Materials & Manufacturing

Materials

Currently prosthetics are taking advantage of strong lightweight materials such as aluminum, connected to a carbon fiber socket mold containing a silicone socket liner. Since the very first-time mobility came into question due to amputation, the goal has remained the same, but now the methods in which people are fulfilling those goals is changing. Materials and computers are becoming more advanced allowing manufactured to push the limits of what their devices can do. The introduction of CPU controlled gait has dynamically changed the possibility for the end outcome of what a mobility device can be and how they are operated or respond to the human body. Doctors are now experimenting with limbs that are controlled externally with neuro connections, allowing the device the understand the signals the brain is making and respond to the accordingly, thus changing the landscape of current materials used (Rajak, 2015).

Manufacturing

The manufacturing process for prostheses is much like any product, where standardized components are made in bulk in a factory, then sent out to the manufacturer’s distributors. The key difference with prosthetics is that each device is made to order and completely custom. When the parts reach the end user, they have been assembled to fit him/her in the best possible way. Furthermore, the connection point, the socket, is completely custom. Without a custom construction for the socket the user would have difficulty moving or feel burdened and clunky.

Sustainability

Benchmark Sustainable Initiatives

Many companies who manufacture prostheses and other mobility aids utilize aluminum because of its strength to weight ratio, and composite materials such as carbon fiber for the same reason. The problem that needs a solution is that some components are unable to be mass produced. So, a material that is sustainable and still able to be utilized in the same manor needs to be introduced. Carbon fiber is non-recyclable and aluminum is only partially recyclable.

Nanocellulose (nano structured cellulose) a wood-based pulp fiber extracted from plants is used to reinforce plastics, and is reported to improve the mechanical properties of thermosetting plastics such as PLA (polylactic acid), and are more recently being introduced into elastomers and polycarbonates creating a more sustainable yet durable and mechanically sounds finished product. These bioplastics are also reported to be used in the design and manufacture of transparent haptic relays which will play a major role in the final design (Kim, 2015).

Additionally, research was conducted into the use of materials such as artificial bone as a substitute to aluminum and or any of the other supporting structures of the brace. The calcium phosphate artificial bone, which is osteoconductive and osteoinductive; is a strong, biodegradable material, that under the right circumstances and research could potentially be a self-healing material with some external stimulation. The material is also on par with aluminum for strength to weight ratio and is currently being used to help restore bone degradation as a paste, and 3D printed as implants for patients with sever trauma/bone loss.

Health

Immediately after the procedure of amputation, the health of amputees becomes an issue, not to say the health of someone who is expecting amputation surgery isn’t important. The reason for the increased health risk is not only due to the recovery from surgery; limb loss, bone deterioration, blood loss, scarring, etc.; rather health is mostly affected by what is happening post-surgery. Despite the high-tech solutions to amputation, prosthetics users eventually find physical effects related to the method of suspending the prosthesis on the residual limb.

The environment within a prosthesis liner has the potential to be a hub for bacteria causing; increases skin temperature, sweating, heat rash, blisters, contact dermatitis, abrasions, and even ingrown hair. These skin issues can progress to very dangerous conditions and infections.

Furthermore, using a lower-limb prosthesis can lead to issues concerning postural alignment, muscle imbalances and strains, and gait abnormalities. The incidence of back pain among lower-limb amputees ranges around 80%. The residual limb is susceptible to deep tissue injuries from forces due to prosthesis use. Intact limbs of lower-limb amputees are much more likely to develop joint and bone problems such as arthritis as amputees habitually load the intact leg more (LaRaia, 2010). Additionally, the body during moments of quite stance must be allowed the freedom of motion in order to achieve maximum balance efficiency. Without the haptic response/information from one or even both legs, balance and locomotion become a difficult task. Virtually all neuromusculoskeletal disorders result in some degeneration in the balance control system (Winter, 1995).

Safety

The locomotion of the human body is an active, dynamic event in which the body is constantly subconsciously adjusting to the environment and how it is overcoming obstacles, elevation change, and change in direction. As a result of the dynamic nature of mobility specific pivot points associated with mobility must accessible to the user and allow for freedom of motion while offering support to the musculoskeletal system (Winter, 1995).

Living with lower limb amputation places users at greater risks of falling. Minimizing risks means the awareness of many factors, some of which include;

reducing travel over uneven or loose surfaces such as rugs or gravel, observing the path of travel watching for hazards, staying mindful of inclines/declines, cluttered spaces, adequate lighting and the use of grab bars. Even tasks that seem simple or mundane such as bathing or using restroom facilities can be extremely dangerous for even the most able-bodied amputees without the aid of grab bars or some form of support (Cristian, 2006).

Final Design

The aim of the proposed product is to enhance the mobility of amputees by restoring some elements of haptic response and stretch reflex, while contributing to the support of body post lower-limb amputation and allowing the offering enhanced mobility through the combination of ergonomic factors associated with the support structure and full-body human interaction. The final design will incorporate sustainable aspects for user health, safety, and environment.

In regards to health the final design will have a redesigned socket that will utilize nanocellulose, being that it is breathable, antimicrobial, and has the ability to be soft/flexible and rigid/strong. The main supporting structure will also aim to reduce forces on the residual limb by having open bottom style socket that redistributes the forces from locomotion to the hip and spine creating a more natural gait. The prostheses will also include shock absorbers to dampen the impact of walking located at the knee and ankle.

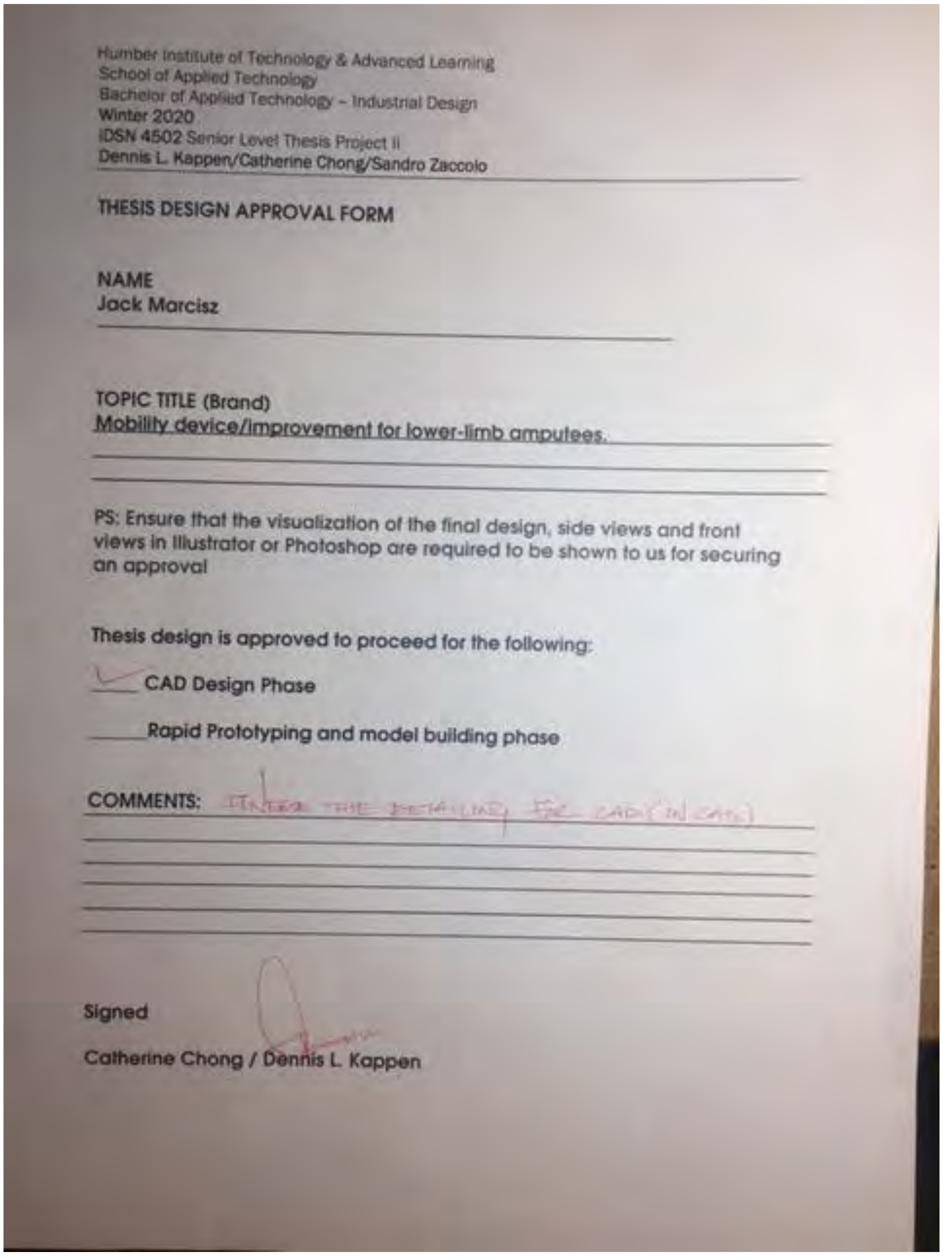
Safety will be addressed by improving balance by incorporating neural transmitters in the socket liner and the spine pack. The transmitters will be constantly feeding information to the user about the position and forces on the prostheses. Furthermore, the ankle will be sending and receiving information about the users position and posture because of the neural transmitters helping them with balance during quite stance and locomotion.

Lastly, environmental concerns will be addressed by utilizing nanocellulose. Its ability to be implemented in a majority of the parts as a stand-alone flexible foam or a reinforcing material for thermosetting plastics means a lessened impact on plastic waste as nanocellulose is derived from plant fibers and is biodegradable. Aluminum will still have to be utilized as the main structural supporting system.

Conclusion

In conclusion, new materials and manufacturing methods are improving the prostheses industry, though some of the parts have to be custom made for the individual user. As improvements and innovation move forward, far better materials will be made available at lower costs monetarily and environmentally creating a more sustainable industry in mobility aids.

Appendix VI: Topic Approval Form



Humber Institute of Technology & Advanced Learning
School of Applied Technology
Bachelor of Applied Technology – Industrial Design
Winter 2020
IDSN 4502 Senior Level Thesis Project II
Dennis L. Kappen/Catherine Chong/Sandro Zaccolo

THESIS DESIGN APPROVAL FORM

NAME
Jack Marcisz

TOPIC TITLE (Brand)
Mobility device/improvement for lower-limb amputees.

PS: Ensure that the visualization of the final design, side views and front views in Illustrator or Photoshop are required to be shown to us for securing an approval

Thesis design is approved to proceed for the following:

✓ CAD Design Phase

____ Rapid Prototyping and model building phase

COMMENTS: [illegible]

Signed

Catherine Chong / Dennis L. Kappen

Humber Institute of Technology & Advanced Learning
Bachelor of Applied Technology – Industrial Design
IDSN 4002 Senior Level Thesis 1
Catherine Chong, Dennis Kappen, Sandro Zaccolo

School of Applied Technology
Fall 2019

THESIS TOPIC APPROVAL

STUDENT NAME: Jack Marcisz

TOPIC TITLE:

How may we improve the mobility of people living with lower-limb amputations?

TOPIC DESCRIPTIVE SUMMARY:

Amputation is the surgical removal of all of or part of a limb or extremity such as an arm, leg, hand, toe, or finger. The most common type of amputation is a complete or partial lower limb amputation due to vascular diseases such as diabetes and peripheral artery disease. The removal of a limb is traumatic and life changing event, which forces the people involved to make drastic changes in their lives in order to cope with the disability. After a major amputation, the main goal of rehabilitation is to return to as normal a life as possible. A major factor playing against those who have had a lower-limb amputation is their mobility. Partial or total removal of a major supporting limb not only causes disfunction of mobility, but also many physical ailments or relating connective tissue and human ergonomic factors such as: hip displacement, spinal torsion, balance, reduced mobility, pain, and posture. This change causes those with the new disability to adopt new methods of transportation in order to regain mobility without relying on others aiding them. The aim of this project is to develop a product that will improve the mobility of those who have suffered a lower-limb amputation, improving their quality of life and reducing the ailments that come with it. Research was conducted to gain insight on common issues afflicting amputees. The proposed product will take into consideration the current methods and factors involved in the mobility of amputees, and suggest a useful and feasible solution. Those affected by reduced mobility due to lower-limb amputation will be able to efficiently and comfortably enhance their mobility while reducing strain, returning them to optimal mobility performance.

Student Signature(s)

Date SEPT. 29, 2019

Instructor Signatures

Date