BME 301
2/25/2015

"U-Cube" Intensive Physical Therapy Unit

Client: Matt Jahnke

Adviser: Krishanu Saha

Team Members:

Jon Elicson – Team Leader, BSAC

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Abstract

Every year, millions of people worldwide suffer a traumatic brain injury. Often, these injuries interfere with the strength and motor skills of the afflicted. Physical therapy is essential in restoring muscle strength and control for many people affected by a TBI. The proposed U-Cube provides a solution for anchoring the customizable supports utilized in intensive physical therapy programs. These physical therapy programs use targeted support or resistance of specific sections of a patient's body to enhance the value of physical therapy sessions. The U-Cube hopes to improve upon prohibitively expensive commercial systems by providing a low cost alternative. For evaluation of the U-Cube System, a patient suspension system was designed utilizing a commercially available harness. The harness and U-Cube are to be used in conjunction to perform gait training exercises in order to validate the safety and utility of the U-Cube design.

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Introduction

About the Client and Adviser

The Client

The client, Matt Jahnke, is currently the Adult Program Director at United Cerebral Palsy of Greater Dane County, a nonprofit organization dedicated to raising cerebral palsy awareness in Dane County, Wisconsin. His website houses many links to the various programs they offer, which provide youth resources, respite care, support services, and therapy to individuals of all ages (8). Mr. Jahnke, a UW-Madison alumnus, has been the client for several previous design projects at the university related to cerebral palsy rehabilitation and therapy. For this current design project, Mr. Jahnke requires that a device be made to therapeutically treat both traumatic brain injuries and other physical disabilities. He also requires that an instruction manual and materials list be created, which he will then upload to UCP Dane's website. This will allow for any individual who wishes to recreate this semester's design prototype to do so, thus providing an alternative to other commercially available models.

The Adviser

Kris Saha holds a Ph.D. in Chemical Engineering granted to him by the University of California, Berkeley. He also has a M.Phil in Biotechnology from the University of Cambridge and a B.S in Chemical Engineering and Chemistry from Cornell University. Dr. Saha was a Postdoctoral Fellow at the Whitehead Institute for Biomedical Research at MIT/Harvard University prior to becoming an Assistant Professor at the University of Wisconsin-Madison. Dr. Saha also is the principal investigator at his human stem cell engineering lab housed at the Wisconsin Institute for Discovery. He has been awarded three patents, numerous awards such as the Branco Weiss Fellowship, and has been published upwards of twenty times (7).

The Occupational Therapist

Amanda Miller is an occupational therapist at the Madison Area Rehabilitation Center. At this facility, she sees approximately 25 different patients. She would like us to design a cage that she can use in her facility to help rehabilitate her patients through the use of intensive physical therapy. She has noted that insurance does not provide much funding for disabilities after the patient has reached 21 years of age, and that there is not currently an affordable physical therapy unit she can use to help her patients improve their balance and gait. As a result, she would like us to design and manufacture a physical therapy unit that she can use at her facility.

The Patient

Our patient, Roberto, is a 5'5" and 150 lbs. He is a Hispanic male who is in his late 50s, and was previously involved in gang related activities. He has lost a significant amount of his brain function and motor skills as the result of a gunshot wound that was inflicted approximately 30 years ago. The result was a traumatic brain injury and lasting mental and physical disabilities. His occupational therapist, Amanda Miller, used to see him weekly in order to conduct physical therapy. Unfortunately, his insurance has recently stopped paying for these visits, and as a result, he has lost his ability to walk unaided (a task he was previously able to accomplish with weekly therapy). Because of this, Amanda Miller would like use the "U-Cube" in order to help Roberto regain his ability to walk.

Background

Traumatic brain injuries, or TBIs, affected roughly 2.5 million people in the United States in 2010 (1). A TBI can be caused by a wide range of events, from falls to assaults or car accidents as seen below in Fig. 1. There are two types of severe traumatic brain injury that a person can experience: closed or penetrating. A closed TBI would result from a concussion or fall, whereas a penetrating TBI would result from blunt force trauma to the head, such as a gunshot (1). Mild injuries result in mild symptoms, such as nausea, blurred vision, dizziness, and/or sensitivity to light and sound (1). Moderate to severe injuries, on the other hand, have more critical symptoms: loss of consciousness, seizures, extreme confusion, and/or a loss of coordination (1). Long term severe TBIs have issues extending beyond the initial injury itself. These long-term issues can impair cognitive function, emotions, sensations, and motor function. In America, there are currently 5.3 million people living with a disability due to a severe TBI, and in 2010 it was estimated that these individuals spent a total of $76.5 billion in medical costs (1). One of the main methods of treating a severe TBI and its long term issues is rehabilitation by intensive physical therapy.

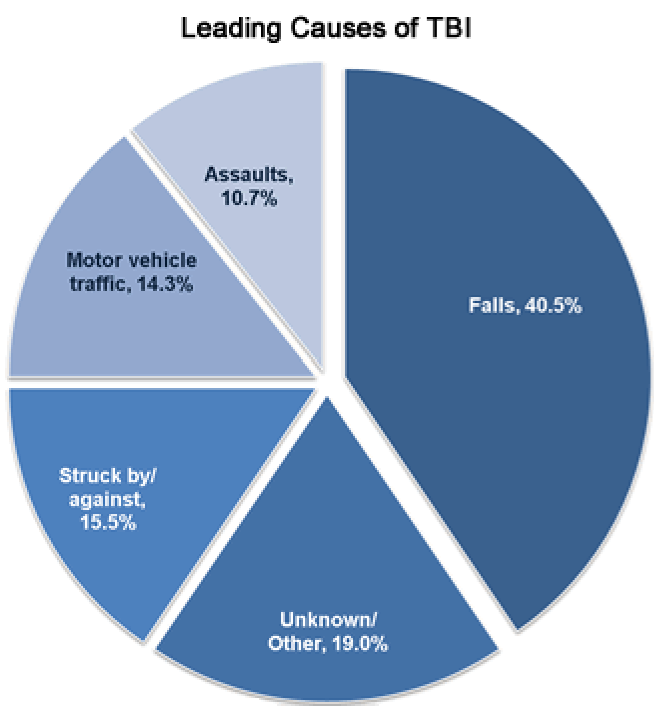


Figure 1: A figure displaying the leading causes of TBIs in America (1).

Intensive suit therapy is a rehabilitation method of physical therapy that allows a therapist to isolate different parts of an individual's body for specific exercises. The patient wears a suit which helps to support their body weight while they perform exercises that help to retrain the brain and normalize movement, making it more automatic. (6) Integrating the suit into a rigid with suspension (like the U-Cube) also helps to support the patient, alleviating this burden from the physical therapist and allowing him or her to concentrate on the exercise itself rather than physically supporting the patient. This intensive therapy can allow the patient to regain balance, gait training, and muscle strength, as well as improve motor skills and coordination.

Motivation

Traumatic brain injuries (TBIs) affect around five million people in America, and they cost the medical system around seventy-five billion dollars a year (1). These injuries can range from mild to severe, and they usually lead to decreased physical and cognitive abilities. The U-Cube in conjunction with a therapy suit is designed to act as an intensive physical therapy unit that can help these people regain mobility and motor function. The U-Cube is not only designed to treat TBIs, but it can also help patients with a variety of other diseases such as cerebral palsy and spinal stenosis. Physical therapy can strengthen muscles and improve flexibility which is an important aspect of regaining mobility and balance. The U-Cube is designed to perform all of these activities, as well as help to improve patients' quality of life. In addition, all of the current devices similar to the U-Cube on the market are very expensive; however, the U-Cube is built to be a fraction of the cost. This will hopefully allow the population to have easier access to this device. Our client, Matt Jahnke, wants us to provide a detailed instructions manual that explains how and where to purchase all materials and put them together to fully construct the U-Cube.

In terms of all of the above, it is necessary that the design is cost effective, easily built, and safe for all to use to help improve the quality of life for people with needs for physical therapy.

Problem Statement

The purpose of this project is to create a rigid cage to suspend a patient for therapeutic purposes. Unlike previous designs, the cage must be lightweight and portable so that it may be transported and must also be made of inexpensive materials so that other patients may duplicate its construction. The cage should be created for use by our patient, Roberto, but should able to be used with the other patients that Amanda Miller has. This project also requires that a suit be either purchased or fabricated and then integrated into the spider cage through the use of elastic suspension. The suit should be capable of fitting Roberto, as well as various other patients that may use it. This first prototype will then be placed at the Madison Area Rehabilitation Center. Finally, an instructions manual and parts list must be created for the U-Cube, which will then be uploaded to our client's website so that other individuals can construct it.

Previous Work

The current project is a continuation from the fall 2014 semester. Three of the current team members continued on with the project, Jon Elicson, Samantha Mešanović, and Jon Leja. The team then acquired a new member, Jake Kanack, since two of the sophomore members, Austin Gehrke and Taylor Marohl, left the project this semester. In the previous semester, the team's focus was on designing the metal cage structure which can be seen below in Fig. 2.

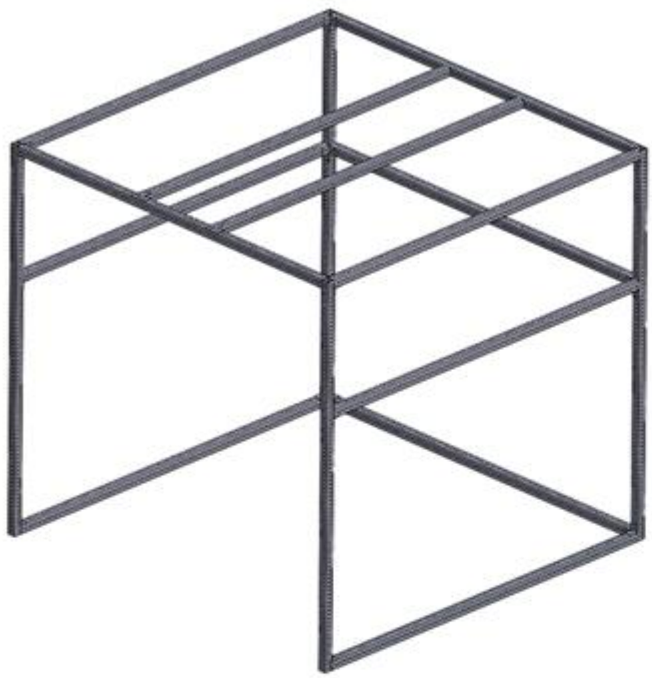


Figure 2: A 3D rendering of the U-Cube that was designed during the previous semester.

The final design was then named the U-Cube and it has a total estimated cost of approximately $1000. The structure of the cage is an eight foot cube, which is enclosed on all sides except for an open-faced front. It was important to keep the front open to allow for easy access into the cage for the physical therapist and the patient. The open-face also makes it easy for the physical therapist to bring in a variety of tools such as a treadmill, table, wheelchair, or Hoyer lift. The cage is constructed from Unistrut metal bars, which are connected with pins and joint fittings. At each corner, there is also a ninety degree fitting that helps to keep it stable, which can be seen below in Fig. 3. Lastly, an important quality of the cage is that all of the materials are easily purchasable, and they can be easily put together by anyone. After the success of the previous semester, the focus of the project has shifted to the harness suit the user will wear, and how to integrate it to the metal structure.

Figure 3: An image of the 90 degree metal fittings that join the struts of the U-Cube.

Design Specifications

In order to facilitate intensive therapy programs, the design must allow for targetable support of specific areas of the patients' body. There must be multiple attachment points for the physical therapy bungee cord systems. The device must be capable of safely supporting the entire bodyweight of a 300 lb. patient. The cage must be large enough to as to accommodate common physical therapy equipment inside, namely a treadmill and a Hoyer lift.

Ethical Considerations

The device must be manufactured in such a way to never endanger the safety of the individual using it. As a result, it was decided that the device should be made from commercially available, thoroughly tested materials that minimize cutting and welding. Once assembled, the device should also provide enough structural support to eliminate any concern that the device should fail. The result could be catastrophic to an already disabled individual. Should the individual ever find that they are unable to detach themselves from the device or find that they are suspended in a manner that endangers their safety, there should also be a mechanism for contacting help or another individual present for supervision. Lastly, the device should have no patent placed on it so that any individual is capable of creating it without the risk of being prosecuted, and ought to provide an affordable alternative to commercially available designs in order to increase the efficacy and affordability of therapy.

Design

Current Therapies

Currently, there are two common therapies that are widely available to individuals with physical disabilities. These therapies include a Spider Cage design and a design for a therapeutic full body suit. These two devices are separate therapeutic systems which are rarely used in combination with the other. Both of these therapies also have significant costs, which are associated with both the cost of the device and the cost of the professional training or supervision required to use the device safely.

Spider Cage

The Spider Cage devices that are currently used in therapy, like the Universal Exercise Unit, contain a fencing unit, which surrounds the individual. The individual then wears a harness, similar to a rock climbing harness, with bungee cords connecting it to the sides and tops of the surrounding fence (3). Inside the spider cage there can be a multitude of different devices for therapeutic application, such as a treadmill, exercise ball, or massage table. The cage is designed for the isolation of specific muscles for intensive therapy (3). The versatility of this device allows for many different types of therapy to occur, and provides a way to keep therapy engaging. However, commercially available cages are rather expensive, with models ranging anywhere from $5500 - $7000 (3).

Figure 4: An image that displays the spider cage being used in conjunction with a treadmill (3).

TheraSuit

The TheraSuit is the current leading design for suit therapy. It was modeled after the Russian space suit, and features a cap, shorts, vest, knee pads, as well as arm and shoe attachments. Each article of the suit is then connected by elastic bands (4). When worn, the TheraSuit promotes muscle normalization by loading the entire body with proportionally distributed weight (4). This suit is complex and intricate, therefore requiring an expensive training program in order to use it. Currently, the program costs $1600/week (4). Furthermore, the TheraSuit is geared mostly toward children, as it only has a “one size fits all” design for adults (4).

Figure 5: A digital rendering the TheraSuit on a child (4).

Design Alternatives

This section outlines and details the three alternative suit designs that can be integrated into the U-Cube.

“DLX Harness”

The first design idea is the DLX support harness, which is manufactured by Biodex and can be seen in Fig. 6. The harness features two nylon straps around the waist to secure the individual in the harness, and there is an interior padding that allows for a more comfortable fit. It does so by both distributing the pressure of the nylon straps around the waist and by creating a softer patient-suit interface. These nylon straps are capable of being adjusted from 28” to 50” (71 cm to 127 cm)(2), thus allowing for the suit to accommodate the multiple patients that Amanda. Miller has in addition to Roberto. The suit also provides additional straps that can be secured around the patient's groin, thighs, and buttocks which can provide additional support as seen in Fig. 7.

Figure 6: An image depicting the DLX suit with its adjustable waist straps and overhead load bearing straps (2).

Figure 7: An image detailing the additional support of the DLX harness (2).

The suit can then be integrated into to the cage by using two load bearing straps that are capable of providing both vertical and lateral suspension for patients up to 300 lbs. (139 kg) (2). These straps can be attached to bungee cords, which can, in turn, be attached to the cage in a dynamic and adjustable fashion. As a result, the DLX suit will allow for a wide range of exercises to be performed which will increase the efficacy of our cage prototype. Furthermore, these straps are also adjustable and allow for the DLX suit to accommodate multiple patients in addition to Roberto (2). This ensures that the U-Cube and suit combination is as customizable as possible.

"The Seat"

The second design consists of a custom fabricated "seat". The frame of the seat consists of two pieces of nylon webbing sewn together in a loin-cloth like fashion. The lower piece provides support for the groin area of the patient, and the upper piece wraps around the patient's waist in order to secure them in the harness. Nylon webbing is an ideal material for the structure of the harness, as a 3/16'' thick piece has a load rating of 9,600 lbs (4354 kg) (9). The inside of the harness is lined with a soft material such as neoprene, in order to improve patient comfort. Attachment to the U-Cube is provided by steel D-rings sewn into the harness. The amount of attachment points can be customized to the client's requirements. The waist size of the harness can be adjusted via horizontal straps sewn to the waist support piece. Buckles on the adjustment straps allow for easy ingress/egress. The primary advantage of the seat design is that the device could be constructed for a fraction of the cost of commercial systems. However, the seat design provides no upper body support for the patient, which could significantly limit the utility of the harness. Additionally, this design requires custom fabrication, which could limit the accessibility of the harness to future clients.

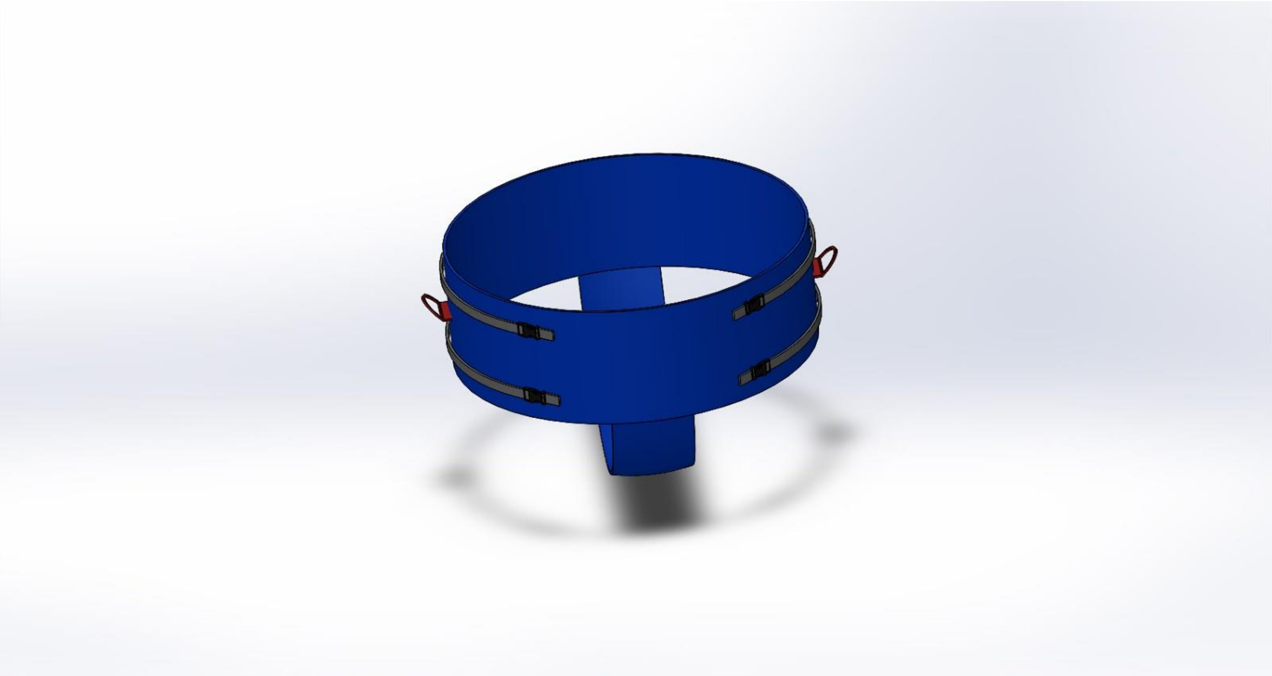


Figure 8: A 3D rendering of the seat design. Buckle models credit Tim Smith

"The iHarness"

The third option for the harness design is the iHarness, seen below in Fig. 9. Online retailer LiteGait, a designer and distributor of various physical therapy tools and accessories, sells the iHarness. The price of the iHarness is $1,500, and this brings it in at the highest cost of the three design alternatives (5). One of the best qualities of this design however, is that it can create a biomechanically-appropriate posture in the patient while they wear the iHarness (5). This was one of the essential qualities that the physical therapist was looking for the in harness. It is important that the suit provides this skill because it is essential that the patients perform the therapy with appropriate posture in order to maximize the efficacy of therapy. The iHarness is also breathable, soft, and flexible (5). This is another trait the therapist was looking for since many of her patients have skin degradation problems.

Figure 9: An image depicting the iHarness being used in conjunction with a medical lifting system (5).

The suit is also easy to clean, so that the therapist can clean it in between the uses of each patient. This is important since the cage will be placed in the Madison Rehabilitation Center and a variety of patients will be using it. This way the iHarness is able to be sanitized and cannot infect any patients. Finally, the iHarness can fit any patient up to an 84” girth, which means that it will accommodate all of the patients at the Madison Rehabilitation Center (5). The iHarness also allows the patient full hip extension which is important since many patients want to focus on standing or walking, and the iHarness will not restrict their hip movement in any way while allowing them to work on this skill (5).

Design Matrix and Evaluation

The harness designs were evaluated primarily through the usage of a design matrix. The amount of physical support provided, patient comfort, and ease of use in therapy were determined to be the most important factors. As the level of physical support provided by the harness is critical to assisting with physical therapy exercises, the amount and distribution of the physical support provided by the harness was assigned the highest priority. The DLX Harness and iHarness scored the highest, as both designs provide support to the lower body, abdomen, and back of the patient. The seat design only supports the lower body of the patient, and consequently scored the lowest in the physical support category. Since the intensive therapy programs for which the U-Cube is designed consist of long therapy sessions several times per week, patient comfort in the harness was also weighted heavily. The DLX harness scored highest in this category, as the pressure exhibited by the harness is distributed in a wide area around the abdomen and back. The seat harness and iHarness were judged to be less comfortable options due to pressure applied to the lower body of the patient. The final vital category was the ease of use of the harness. The DLX harness and seat design scored the highest in this category, as both options do not restrict limb movement. The iHarness scored the lowest in this category because the harness utilizes multiple pieces that need to be attached, complicated usage.

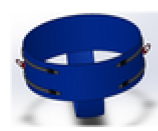
Design: **Criteria (weight)**	DLX 		Seat 		iHarness 	
Physical Support / Distribution of Weight (25)	4/5	20	3/5	15	4/5	20
Comfort (20)	5/5	20	3/5	12	4/5	16
Ease of Use (20)	4/5	16	4/5	16	3/5	12
Adjustability (15)	3/5	9	3/5	9	4/5	12
Safety (10)	5/5	10	2/5	4	4/5	8
Cost (10)	4/5	8	5/5	10	1/5	2
Total (100)	**83**		**66**		**70**	

Figure 10: The preliminary design matrix that was constructed in order to evaluate the 3 design alternatives.

Final Design

As the design matrix shows, the DLX harness was evaluated to be the best harness option. The DLX harness scored well in every category evaluated, and should present an effective solution for the integrating the U-Cube into the gait training exercises desired by the client. At a quoted price of $499, the harness should also fit within the project budget. Additionally, as the U-Cube plans are planned to be made publicly available, the commercial availability of the DLX harness presents a viable suspension option for future independently constructed U-Cube applications. While the DLX harness will be prioritized in future development, all of the harness designs will be presented to Amanda Miller for further feedback.

Future Work

Although the DLX harness has been chosen for a suit design, it still needs to be integrated into the U-Cube physical therapy unit. In order to do so, our design team will make several alterations to the DLX harness in order to increase its functionality. These alterations will be explored during the course of this semester, and will most likely consist of the addition of more load bearing straps and a possible chest support piece that can be fabricated out of additional material. As a result, these load bearing straps can increase the stability and versatility of the suit, and a chest piece can improve posture and allow for spinal deformities to be accommodated. Also, while these modifications will improve upon the suit, the suit can still be listed as a commercially available item on the materials list for the cage.

Our team would then like to perform additional structural analysis on the U-Cube. This will most likely take the form of a finite element analysis using SolidWorks or ANSYS. The U-Cube was previously designed using a SolidWorks assembly; however, we have run into a few errors with respect to analyzing the U-Cube on SolidWorks. This is mainly due to the fact that there are many individual parts on the design, and while SolidWorks is an excellent 3D rendering program, it does not excel at performing a finite analysis of a complex assembly file.

Lastly, our team has recently submitted a Bellows Grant funding application through United Cerebral Palsy of Greater Dane County. This application was accepted on a local level, and is now waiting for approval on the national level. Once this application is accepted, our team will be able to get funding for our design project and hopefully be able to construct a functional prototype by the end of the semester that can be placed at the Madison Area Rehabilitation Center. A parts list and instruction manual will then be created once a prototype has been fabricated and will be uploaded to Matt Jahnke's website.

Appendix

Product Design Specifications

Team Members: Jon Elicson, Jon Leja, Samantha Mešanović, Jake Kanack
Date: February 4, 2015

Function

A spider cage (or the U-Cube prototype) and suit are devices used by therapists to work with people (usually children) who have physical disabilities. Spider cages provide targeted support to an area of the patient's body through bungee cords connected to a suit, harness, or band, and assist with intensive physical therapy programs. The support provided by the bungee cords is adjusted by changing the strength and attachment locations of the cords. Spider cage devices are available commercially, but are prohibitively expensive. The desired product must be relatively inexpensive, collapsible for transport, and created utilizing off-the-shelf components for widespread applications. The design must also feature a suit for use in conjunction with the cage.

Client Requirements

- The device must work for a variety of individuals of varying weight, age, and height in addition to Roberto.
- The device must include some apparatus to connect the individual to the cage. This apparatus will most likely take the form of elastic suspension bands of varying length and resistance.
- The device must cost less than the commercially made devices priced at $5500.
- The device must have a simple fabrication process using easily obtainable tools and materials.
- The device must include a detailed instruction manual and parts list to assist in assembly that will be uploaded to UCPdane.org.

Design Requirements

1. **Physical and Operational Characteristics**
    a. *Performance requirements:* The device should be able to withstand day to day use, and be durable and light enough to be disassembled and transported. The spider cage should provide enough room to allow for the individual to translocate around the cage in each direction. It should provide attachment locations for the necessary elastic straps, and allow these straps to attached or detached to the individual using the cage. This device should allow for an able-bodied individual to facilitate therapy without a trained professional if they so choose, but this is not recommended.
    b. *Safety:* The spider cage should be strong and stable enough to allow for rapid movement and loads that will exceed the normal weight of the individual.
    c. *Accuracy*: The support provided by the suspension system must be adjustable to target therapy relevant sections of the patient (e.g., a specific limb). The strength of the support provided by the suspension system must be adjustable.

d. *Life in Service:* The device must be able to be used for 2 hour long therapy sessions 5 times per week without wear. The device should also be stored in a temperature controlled environment, and away from excessively humid or dry air.
e. *Operating environment:* The device is intended for use in the individual's home or in a physical therapist's facility. The device should be capable of being tailored to a specific individual for extended periods of use, but have the capability to be adjusted to accommodate another individual. The targeted use is for patients of all ages, placing an emphasis on the ability of the cage and suit to accommodate small children.
f. *Ergonomics:* The elastic bands must be reachable and easily adjustable.
g. *Size:* The cage must be tall and wide enough to accommodate anyone. Different attachments must be small enough so that they can be handled easily. The suit must also be capable of being adjusted to fit multiple individuals.
h. *Weight:* The device should be transportable.
i. *Materials:* Materials for the cage itself should not be sharp. Materials that are resistant to corrosion and rust should be used. The suit must also be made of materials that will not result in skin degradation.
j. *Aesthetics, Appearance, and Finish:* The device should look professionally assembled. Elastic bands should be color coded or labeled in another way in order to identify different strength bungee cords for ease of use.

2. **Production Characteristics:**
   a. *Quantity:* Plans and an instruction manual for the unit will be uploaded to ucpdane.org, with the intention of creating a device that could be readily produced by future patients or patient care providers. Accordingly, the device must be constructed utilizing parts and tools that are commercially available. However, the first prototype will be placed at the Madison Area Rehabilitation Center for use by an occupational therapist.
   b. *Target:* Current research has found that a similar device would cost about $5500. The product can most likely be mass produced, however current manufacturers only custom produce each product. The client would like the device to be as inexpensive as possible without there being an exception to the device's safety and functionality.
3. **Miscellaneous:**
   a. *Standards and Specifications:* The device must include a materials list and an instructions manual so it can be uploaded online on the United Cerebral Palsy of Greater Dane County's website for fabrication by other individuals. The cage and suit will not be required to be approved by the FDA for use, but will need to have a finite element analysis performed on it to ensure a reasonable factor of safety for personal use after construction by a third party who does not necessarily have professional training.
   b. *Customer:* The customer is Matt Jahnke from United Cerebral Palsy of Greater Dane County. Mr. Jahnke requires that a cage prototype be constructed for which an instruction manual and parts list will be created, and that the first prototype is placed at the Madison Area Rehabilitation Center. These lists will then be uploaded to ucpdane.org, thus allowing any individual to download and construct the cage prototype. The cage also has the possibility of be constructed in a residential environment in the absence of commercial

tools. As a result, the cage should be able to be assembled using common household tools and hardware.

c. *Patient-Related Concerns:* It is recommended that the patient be supervised and assisted during therapy sessions that utilize the cage prototype.

d. *Competition:* There is no commercial competition in the price range desired by the client. There are several models on the internet for approximately $5500 (3).

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