The Design of an Exoskeleton Arm Brace for Therapeutic Use to Address Ataxia

A Major Qualifying Project Report:

Submitted to the Faculty of

Worcester Polytechnic Institute

In partial fulfillment of the requirement for a

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Approved On:

April 28, 2016

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Abstract

Ataxia is a degenerative muscle disease that affects all ages, typically affecting gross motor skills, and may be diagnosed as sporadic, hereditary, or as a symptom of other pre-existing medical conditions. The primary goal of this project is to develop a device to be worn on the arm of a patient affected by ataxia. This device is designed to allow every-day activities to become less strenuous, thereby increasing the mobility of each affected individual and limit unwarranted muscle spasms. The final device consists of two adjustable metal bars attached to two separate sleeves with a gasket located at the elbow. The gasket adds an adjustable friction element, and this device incorporates the six major design requirements: adjustability, accommodation, cost, materials, weight, and forces.

Acknowledgments

The team would like to acknowledge the following people for their influence in the completion of this project:

Professor Eben Cobb: For advising the entire project in each aspect.

Dr. Carol Cobb: For advising with edits on this paper.

Barbara Furhman: For making the purchasing process go smoothly especially with short timeframes.

Steve Putnam: For assisting with the machining of the device.

Alino Te: For assisting in construction and the machining of the device, and the resistance calculations.

Authorship

All members contributed equally to each element within this project including this report.

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1: Introduction

There are more than 1000 neurological disorders that have been discovered and more than 50 million people around the world are diagnosed with a neurological disorder every year (Oregon Health and Science University [OHSU], 2016). A neurological disorder is described as any disease that affects the body's nervous system and may impact the physical and behavioral aspects of the body. There are many diseases that fall within this category, such as Alzheimer's, bipolar disorder, cerebral palsy, epilepsy and Parkinson's disease. The neurological disorder that this paper will investigate is ataxia, which is defined as a disorder that results in abnormal, uncoordinated movements (Johns Hopkins University [JHU], 2016). Within this paper we will further define ataxia and what causes it, the types of symptoms that are seen with each type of ataxia, as well as the treatments and devices that are currently available.

1.1: Goal Statement

The lack of communication with therapists caused our team to change the scope of the project. Our initial target was to design a brace that could be used by therapists in order to support the patient through their rehabilitation process. Due to the miscommunication and potential law violations of sharing patient information, reaching out to therapists became unavailable. Therefore, rather than creating a brace for rehabilitation purposes, our objective changed to design a brace that could be used to build muscle tone in the patient's arms in everyday activities outside of their rehabilitation visits. This device would be used during simple tasks that the patient would do at home, while enforcing muscle strengthening. As the scope of our project adjusted to the given circumstances, our goal statement shifted as well. Our final goal statement for this device is as follows:

To develop an adjustable arm brace for patients who suffer from ataxia that would warrant movement and muscle formation.

1.2: Motivation for the Project

The motivation behind our project stemmed from our advisor, Professor Eben Cobb. Through his resource of a therapeutic center, he became aware of another patient, a young boy who has ataxia. The boy was working on muscle strengthening and gaining control of his spastic arm movements. The therapist that was working with the child mentioned that the boy wanted to be able to perform normal functions without having spastic episodes, whilst gaining muscle. The therapist was working on light muscle training in order to create muscle formation for the boy, as well as improving his coordination skills. The boy's motivation to be in therapy was so he could gain control of his arm movements and play the Wii just like all of his friends.

As discussed previously, even though we were not allowed to talk directly to the therapist that worked with the boy, or the boy himself due to privacy policies, we kept the child in mind while creating our device. Our device would provide assistance in building muscle that would allow the child to play the Wii. We made our device adjustable, lightweight, user-friendly, and with multiple resistances. Therefore, this device could be used for a wider audience in addition to helping the child that was part of the original motivation for the project.

2: Ataxia

2.1 What is Ataxia?

Ataxia is a movement disorder that is associated with many diseases and disorders. The word “ataxia” comes from the Greek word “a taxis” meaning without order or incoordination (National Ataxia Foundation, 2016). Those that suffer from ataxia have trouble with coordinated movements. They are faced with balance issues and inadequate postural control, which can cause a simple task such as walking, to be a complicated endeavor. In addition, activities that require fine motor control such as speaking clearly, swallowing, writing and reading may become abnormal with those who suffer from ataxia (JHU, 2016). Different types of ataxia reveal different symptoms, but most commonly affect the fingers, hands, arms, legs, speech ability and eye movement.

2.2 What causes Ataxia?

Within the human body, the central nervous system (CNS) is responsible for integrating sensory information and responding properly. The CNS consists of two main elements, the spinal cord and the brain (University of California [UCB] Berkeley, 2016). Figure 1 depicts the sections of the CNS.

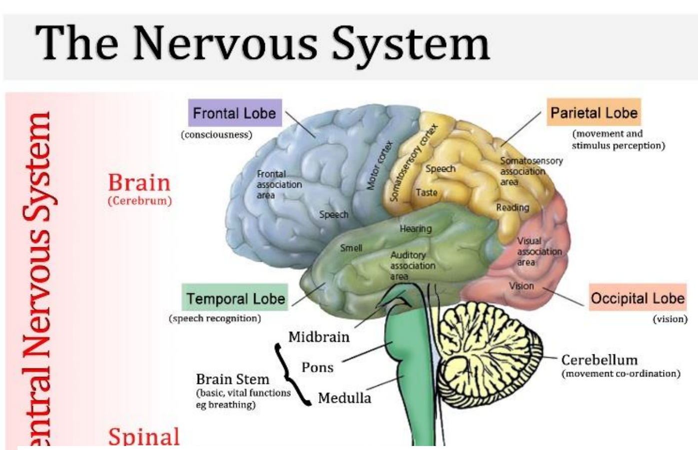

Figure 1- The Central Nervous System

The spinal cord serves as the communication center for signals between the brain and the remaining parts of the body, and the brain integrates the sensory signals with the proper body function. The cerebellum, located at the base of the brain, controls coordination within the body. For those who suffer from ataxia there is damage, degeneration or loss of nerve cells within the cerebellum and peripheral nerves that connect the cerebellum to the body's muscles (Mayo Clinic, 2014).

There are many traumatic events or diseases that may inflict damage to the spinal cord and brain which could possibly result in ataxia. This includes the following, yet is not limited to, stroke, head trauma, multiple sclerosis, tumors, and toxic reactions.

3: Main Types of Ataxia

There are three main types of ataxia; hereditary, idiopathic late onset cerebellar (ILOA) and acquired. The type of ataxia that our project and paper are going to focus on is hereditary ataxia. This is due to the fact that more than half of the diagnoses of ataxia are hereditary. Within this chapter we will go in depth on hereditary ataxia and the three phases that are seen within this category.

3.1 Hereditary Ataxia

Hereditary ataxia is the type of ataxia that is inherited genetically. The symptoms from hereditary ataxia tend to develop slowly over many years (Mandal, 2013). Within the category of hereditary ataxia there is autosomal dominant and autosomal recessive. One of the most frequently diagnosed types of autosomal dominant hereditary ataxia is Machado-Joseph Disease. Symptoms of this type of ataxia arise can as early as five to six years of age and as late as 70 years of age.

This disease occurs most often in those of Portuguese or Azorean descent. The symptoms tend to start with a slow progressive clumsiness in the arms and legs, and a staggering/lurching gait. Difficulty with speech and swallowing, impaired eye movements, and lower limb spasticity follow. In more severe cases, dystonia may develop, which is the permanent twisting of limbs and body through sustained contractions. In addition, fasciculation's (twitching) of face or tongue can occur, along with possible problems with the automatic nervous system. These symptoms can vary widely, even within the same family, although the majority of these symptoms worsen with time.

Within the category of hereditary ataxia, there are three different stages during which the symptoms can begin to develop. The three stages are broken down in the table below. Although each patient is different and shows symptoms at different times within their life, this is a standard progression within the majority of people diagnosed with hereditary ataxia.

Table 1 Comparison of Stages within Hereditary Ataxia

Type	Name	Age Developed	Symptoms
1	Early Onset	10-30 years	Faster progression that includes more dystonia and rigidity than actual ataxia
2	Onset	20-50 years	Most common, includes intermediate progression, prominent ataxia, spastic gait and an enhanced reflex response
3	Late Onset	40-70 years	Progresses relatively slowly with equal amounts of peripheral neuromuscular movement difficulties

For the autosomal recessive category within hereditary ataxia, the most common diagnosis is Friedreich's ataxia. Friedreich's ataxia makes up around half of the hereditary cases seen by medical professionals (Mandal. 2013). Symptoms of Friedreich's ataxia tend to begin appearing in childhood between the ages of eight and 15 years (Mandal, 2013). In less than 25% of the cases, symptoms can start to develop in adulthood. Gait ataxia is the first symptom to develop, which manifests itself in difficulty of walking. Eventually this spreads to the arms and torso, with an additional loss of sensation in the extremities. Loss of tendon reflex in the knees and ankles often develops, as well as scoliosis: curvature of the spine. Dysarthria (slowness and slurring of speech) will develop and will progress as the muscles weaken in time. Later in the progression, hearing and vision loss may occur as well as potential chest pain, shortness of breath, and heart palpitations. These symptoms stem from the various forms of heart disease that often accompany hereditary ataxia. Usually around 10-20 years after the first symptom develops, the patient is confined to a wheelchair.

4: Overall Symptoms of Ataxia

As mentioned previously, ataxia is a degenerative muscle disorder that affects the muscles and can make daily activities challenging or nearly impossible. Ataxia is not a disease by itself, rather a side effect from another disease or injury. The symptoms of ataxia vary based on the type of ataxia present in the patient. Symptoms also vary in the degree of severity based on the form of ataxia. However, most of the symptoms involve some type of reduced coordination of the limbs. This inability to move in an organized manner can lead to difficulty walking and weakened motor skills. For example, a patient suffering from an inability to coordinate the movements of his or her body would have difficulty tying their shoes, or typing on a keyboard. With this lack of coordination, the patient may experience difficulties or changes in their speech patterns. Words become challenging to form and speech may become slurred. More severe symptoms include complete loss of muscle coordination and balance, loss of speech, increased exhaustion, and mood problems (Mayo Clinic, 2014).

In regards to balance, the patient may have difficulty standing or sitting in an upright position. Patients with ataxia may struggle with balancing on moving platforms such as elevators or a moving subway. This can lead to bodily harm if the patient cannot stand or walk without stumbling or falling and may require the use of a brace, cane, or a walker (JHU, 2016). With the loss of coordination, the patient may find that they lack the ability to form coherent sounds in order to communicate. Additionally, a patient with ataxia may not be able to control the volume or pitch of their voice (Delgado & Boskey, 2015). Swallowing may also become an issue, resulting in choking as a possible hazard (JHU, 2016). A patient's eyesight may be affected, causing them to have blurred vision, making it difficult to read, or causing difficulty following the movement of objects (JHU, 2016). Other symptoms may include uncontrollable or repeating eye movements.

Increased exhaustion and fatigue may also be a side effect of ataxia. This is due to the patient requiring more energy than normal in order to compensate for the lack of fluidity in their movements. This will also cause the patient to focus an increased amount on tasks such as walking or speaking, causing them to feel mentally exhausted, leading to headaches and dizziness. (JHU, 2016).

If the cerebellum is affected, the patient may experience behavioral or mood problems. It may cause short-term memory loss, an inability to plan and make decisions, or a failure to recall information in the correct order. It can also cause mental disorders such as depression and anxiety (JHU, 2016). In some cases, patients have reported a loss of touch, or the ability to feel temperature or sharp pain. Reflexes may also weaken or stop completely causing patients to lose the "knee jerk" reaction to stimuli (Muscular Dystrophy Association [MDA], 2016).

This wide range of symptoms is due to the many different types and severities of ataxia. This muscle disorder can affect anything including: movement and coordination, hearing and vision loss or impairment, an increase in speech difficulty, increased fatigue, behavioral or mood changes, and sensory disruptions or loss (MDA, 2016). The table below shows "Clinical Differences Between Basic Types of Ataxia" researched by Kadriye Armutlu at Hacettepe University in Turkey. It highlights the category of symptoms based on the type of ataxia.

Table 2- Clinical Differences Between Basic Types of Ataxia

Type	Cerebellar Ataxia	Sensory Ataxia	Frontal Ataxia	Vestibular Ataxia
Head posture	Upright and sometimes fixed	Leans forward	Leans forward	Upright and definitely fixed
Trunk posture	Stooped-leans forward	Stooped-upright	Upright	Upright
Stance	Wide-based	Wide-based	Wide-based	Wide-based
Initiation of gait	Normal	Normal-wariness	Start hesitation	Normal
Postural reflexes	+/-	Intact	May be absent	+/-
Steps	Stagger-lurching	High-stepping	Small-shuffling	Normal
Stride length	Irregular	Regular	Short	Normal
Leg movement	Variable, ataxic	Variable - hesitant and slow	Stiff, rigid	Normal
Speed of movement	Normal-slow	Normal-slow	Very slow	Normal-slow
Arm swing	Normal, exaggerated	Normal	Exaggerated	Normal
Turning corners	Veers away	Minimal effect	Freezing-shuffling	Dysequilibrium
Heel-toe test	Unable	+/-	Unable	Unable
Romberg's test	+/-	Increased unsteadiness	+/-	-
Heel-shin test	Usually abnormal	+/-	Normal	Normal
Falls	Uncommon	Yes	Very common	Common

5: Categories of Ataxia

Researchers have divided opinions when it comes to agreeing upon how many categories ataxia should be split into. Besides the stages listed above, these categories revolve around the symptoms and the functions that they inflict. The four categories that are most commonly agreed upon are: sensory, vestibular, cerebellar and frontal ataxia. Each of the four types listed affect different parts of the body and create issues with functions that rely on those certain parts. The term “mixed ataxia” refers to when two or more types of ataxia can be observed from the list above (Armutlu, 2010). For example, multiple sclerosis contains cerebellar, sensory, and vestibular ataxia.

5.1 Sensory Ataxia

Ataxia affects several sensory and motor regions of the central nervous system, as well as peripheral nerve pathology. Generally, any problems in the interconnection of the proprioceptive, visual, vestibular systems, or cerebellum can be an advancement towards ataxia (Armutlu, 2010). Loss of proprioception, which is sensitivity to a joint, is described as sensory ataxia. In short, dorsal columns of the spine that carry proprioceptive information to the brain may be affected by a dysfunction in the thalamus and parietal lobes of the brain, therefore those signals are not able to receive that information. Figure 2 shows the sections within the spinal cord.

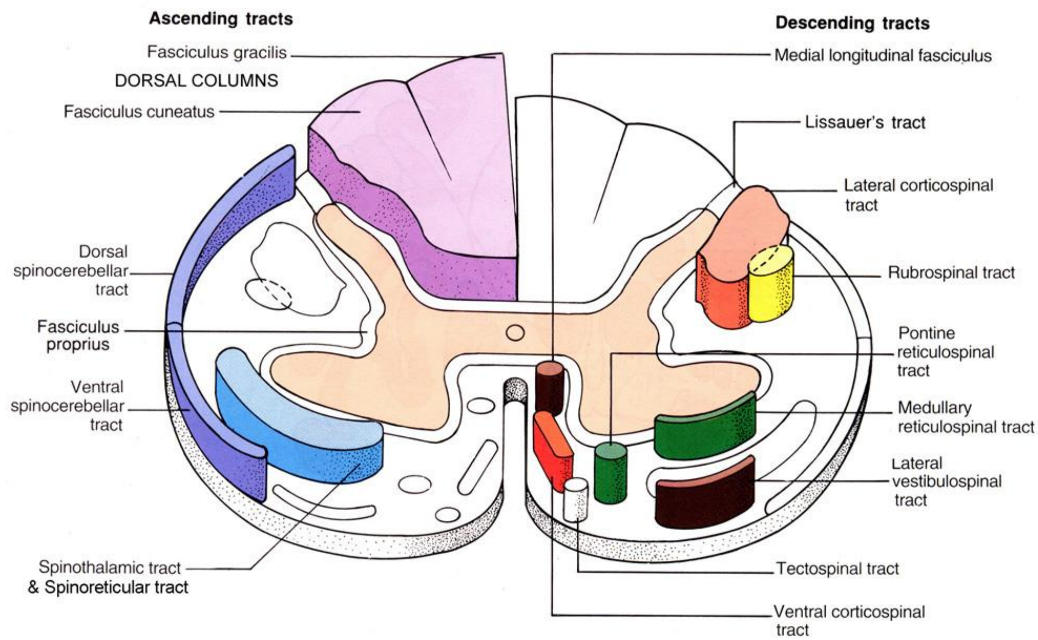

Figure 2 - Sectional breakdown of the Spinal Cord. (AC Brown)

This form of ataxia causes the patient to lose sensory feeling in extremities, joints and other body parts. People affected by sensory ataxia are usually seen with an unsteady gait. This results in a heavy heel strike resembling a stomping motion, and symptoms tend to worsen especially when in visually impaired settings such as a dark or dimly lit environments. These complications make it much harder for sensory ataxia patients to keep proper balance. This category of ataxia can be seen in types of hereditary ataxia, such as Friedreich's and spinocerebellar ataxia, and can also be found in diabetic neuropathy, medulla spinalis, and multiple sclerosis (Armutlu, 2010).

5.2 Vestibular Ataxia

Peripheral or central diseases cause vestibular ataxia, which affects a patient's balance while sitting or standing. When walking, the patient may tend to stagger and lean backwards or to the side. Head and trunk turning motions are often decreased, and is also known to limit a patient's ability to use their peripheral vision. This often causes daily tasks, such as food shopping or crossing the street, to become stressful and almost impossible. Stabilization of the gaze becomes very difficult for vestibular ataxia patients, and can be accompanied by nausea, vomiting, blurred vision, as well as vertigo (Armutlu, 2010). Peripheral vestibular diseases such as benign paroxysmal vertigo, Meiner's, multiple sclerosis, and medullar stroke can be developed due to vestibular ataxia (Armutlu, 2010).

5.3 Cerebellar Ataxia

Acute cerebellar ataxia (ACA), also known as cerebellitis, is a disorder that occurs when the cerebellum becomes inflamed or damaged. The cerebellum is the area of the brain responsible for controlling gait and muscle coordination (Delgado & Boskey, 2015). Cerebellar ataxia can be caused from various issues within the cerebellum. Some of these issues include viruses, bleeding, exposure to mercury and lead, bacterial infections and head trauma (Delgado & Boskey, 2015). Figure 3 highlights and labels the different parts within the cerebellum.

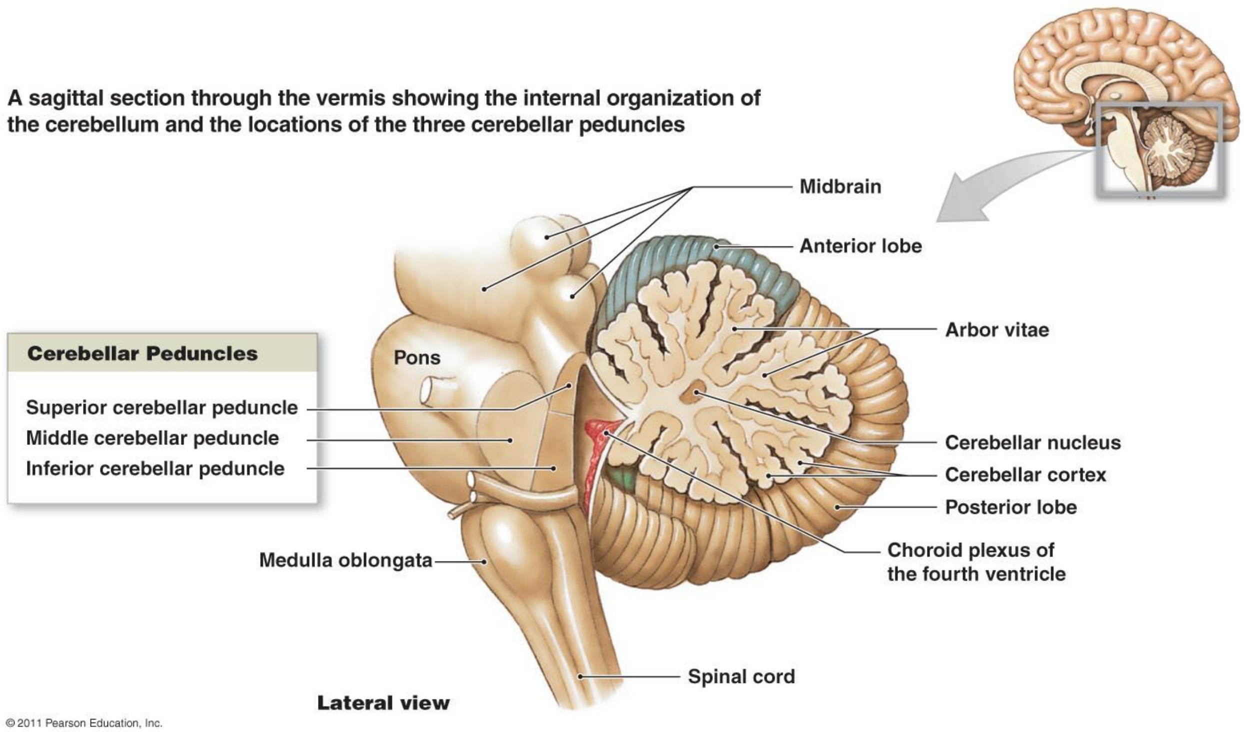

Figure 3 - Parts of the Cerebellum

Multiple symptoms occur from this sort of damage to the cerebellum. Symptoms include impaired coordination in the torso, arms and legs, frequent stumbling, unsteady gait, uncontrolled eye movements, headaches, vocal changes, personality changes and dizziness (Delgado & Boskey, 2015). Of all of the types of ataxia discussed, cerebellar ataxia is the most challenging to deal with. It crosses many areas of function within the human body and has many negative impacts. The most common symptom with those who suffer from this form of ataxia is limited movement of the torso, the neck to hip area. The immobility of the trunk area of the body then restricts the movement of the arms and legs directly. Unfortunately, the prime timeframe for this type of ataxia to develop is within children between ages two and seven (Delgado & Boskey, 2015). There is very little that medical professionals can do due to the rapid progression of the disease. The primary suggestion from these medical professionals to abate the onset of the symptoms is physical therapy.

5.4 Frontal Ataxia

Frontal ataxia, also known as bruns apraxia, is a form of gait ataxia. Patients with this form of ataxia have bilateral frontal lobe disorders. The frontal lobe of the brain is shown within the Figure 4.

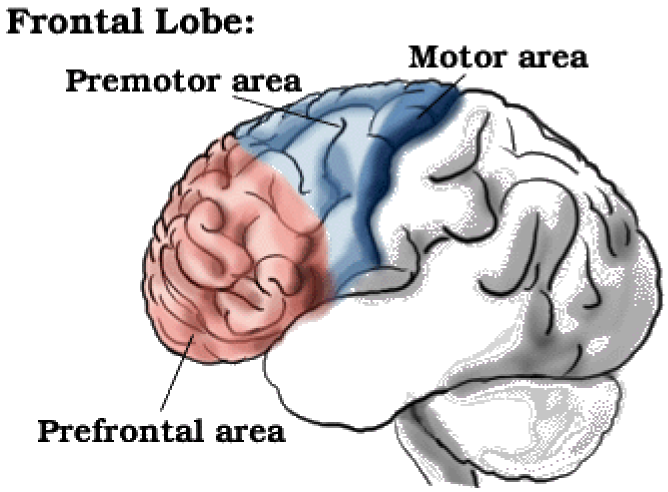

Figure 4 - Frontal Lobe of the Brain

When tumors, abscesses, cerebro vascular accidents and normal pressure hydrocephalus effect the frontal area of the brain, the symptoms of frontal ataxia are seen. The symptoms that result are the inability to stand straight, hyperextension and incoordination between the legs and the trunk of the body. In the most severe cases, patients suffering from frontal ataxia may exhibit signs of dementia, and urinary incontinence (Armutlu, 2010).

6: Treatments

Treatment of ataxia is strictly dependent on the type of ataxia present. However, complete elimination of ataxia does not exist in regards to any of the specific types. Pharmaceuticals have been used to help reduce the effects of the disorder, but cannot completely eliminate the symptoms.

Other tactics that have been used to try to lessen the effects of ataxia are physical and occupational therapy. Physical therapy focuses on a specified plan for an individual patient. The patient focuses on controlling and refining fine motor skills as well as gait training to insure that the patient can feel more confident and comfortable in their own mobility. Out of all of the treatments researched, we found that the one most recommended and most commonly used was physical therapy.

6.1 Physical Therapy

Rehabilitation in the form of physical therapy can lessen the severity of the symptoms and give the patient back some form of independence. Most physical therapy focuses on improving motor skills and reactions. Since there are various forms of ataxia, it is important that the patient first be evaluated to understand the type of ataxia and what symptoms might be present. From there, the physical therapist can determine the appropriate course of action (Armutlu, 2010).

One test used to determine whether a patient has ataxia and to what degree is the Berg Balance Scale. In order to customize every physical therapy schedule to each patient, this test is used to place patients on a scale. This scale is widely used by physical therapists to gauge the patient’s mobility. The test takes approximately twenty minutes to complete and is comprised of a variety of tasks that involve simple motions such as balancing on one foot and sitting down in a chair. The results of the test are graded and given a numerical representation which correlates to a score between 0 and 56. If a patient scores below 20, their condition most likely requires them to be wheelchair bound. If a patient scores higher than a 40 they are considered independent. If a score between 20 and 40 is achieved then the patient is able to walk, but with assistance. The test is used to gage the patient's mobility. An example of the Berg Balance Test can be found within Appendix C.

To improve the physical coordination, different exercises must be used. These exercises can include learning to crawl using both arms and legs, to moving to a sitting position unassisted while also maintaining a relatively stable posture. From here patients can move into standing positions while holding a weight (Armutlu, 2010). Patients are instructed to practice moving the weight from left to right in order to increase both their balance and strength simultaneously. The final step is learning to walk, either unassisted or using an aid, while concurrently flexing upper extremities and moving the head side to side (Armutlu, 2010).

Patients who suffer from sensory ataxia often lose their sense of touch or the ability to feel sharp pain or temperature. For patients with sensory ataxia, it is recommended that they begin by “mechanically stimulating the joint surfaces, muscles and tendons, and decreasing postural instability by improving body awareness” (Armutlu, 2010). Another recommendation to aid sensory therapy is suit therapy. This suit consists of weighted clothing attached to physical therapy bands that help keep the body in place and aligned (Armutlu, 2010). An image of a patient going through suit therapy can be found in Figure 5.

Figure 5 - Suit Therapy Example

6.2 Assistive Devices

Most sources will suggest the use of canes or walkers to aid in walking. A good intermediate step between these two is crutches, either underarm or forearm. The use of a variety of manual and power assistive devices for movement up and down levels, whether it be stairs or a ramp installation, to deal with mobility, strength, and balance issues. Orthopedic braces are suggested to add support to the body while moving around. Knee braces can range from $10 for a simple knee sleeve to around $800 for a brace that allows for almost no weight bearing upon the knee joint. A device that is currently on the market is the image shown below in Figure 6. We used this general concept of this knee brace within our design. Although the knee brace shown within Figure 6 is a motion restriction brace, we used a similar structure to harness and attach the device to the body. For the ease of use and simplicity portion of our device, we modeled our design after Figure 7. This device is primarily used for support for the patient and helps stabilize the desired positioning for the joint.

Figure 7 - Example of Knee Brace

Figure 6 - Example of Knee Sleeve

Orthopedic foot, ankle, and leg braces can provide much needed support to the patient, whether it be for a weakness in side to side foot movement, or an up and down motion. The brace can have differing numbers of straps depending on how involved it is, from just having a tongue under the foot and a strap at the top of the calf, to having the brace wrap around the entirety of the lower leg to lend more support. If minimal support is needed, more aesthetic changes can be made to the brace, such as having the connection between the foot and calf wrap in a way that hides the brace from certain views, whereas the more involved braces resemble a ski boot. These braces are almost always custom made, and as such the process tend to start around $50 and increase in price as the complexity and quality go up.

7: Objective

Objectives are benchmarks, attributes and elements of a design that the client or user has expressed as something they would find beneficial within the device. After acquiring research on ataxia and current adjustable braces that are on the market, our group was able to generate a list of objectives that we wanted to achieve when creating our device. The full comparison of all of the objectives and whether or not certain designs met the objective is shown in Appendix A.

The most important objective that our device revolves around is safety. The device shall not cause any harm or injury to the person wearing the device. There should be minimal possible pinch points within the device, and those that are unavoidable, shall be covered with soft fabric to inhibit skin to metal contact. If the device presented a possibility of causing additional issue and harm, the patient may not find the device worthwhile. They may see the device more as a hindrance than as an aid, which is the exact opposite of the purpose of this device.

The second objective in designing our device was ensuring that it is somewhat affordable compared to the current devices that are on the market. The majority of the devices currently available are extremely complicated and rather expensive. A standard adjustable knee brace costs around $200 (The Brace Shop, 2016). We set a goal to create our device out of easy to find materials that cost less than $75 as well as being simple to assemble. After looking at our final bill of materials, which can be found within Appendix D, the total price to make the device was $52.05. We reduced the price by 26 percent compared to the standard brace cost.

Although there were many other objectives, the last one we will discuss is the user friendly aspect of our device. When designing the device, we wanted to keep simplicity in consideration. The easier it is to assemble and attach to the arm, the more likely people will use the device. The device should not be a hassle to use, especially if it going to be used on a daily basis. Within Appendix D there is an assembly guide that gives directions on how to put the device together.

8: Constraints

Constraints are seen as limitations or restrictions that are applied to a project or design that alter the overall product. The team encountered various constraints during this project including project centered and design centered constraints. Two of the main project constraints that were presented within this project were the time and cost. For this project, the final device was completed within 28 weeks. This includes the time to design, build a prototype, design validation testing, and generation of a report with analysis and recommendations. As for the cost portion, our team was limited to $600 for the entire project.

During each of the four terms of the academic year, we created a Gantt chart. Each major deliverable was given its own timeframe and approximate deadline. These charts made it much easier to visualize and compare the order in which each objective needed to be completed.

During our first term, a significant amount of time was dedicated to contacting a therapist in order to help us with our research of ataxia. We reached out to the therapist that was working with the child we were interested in helping in order to understand the patient's needs. As discussed previously, neither the therapist nor the rehabilitation center answered our phone calls or offered to help us with our data gathering. Therefore, our research focus shifted to research papers and medical references.

We began by brainstorming several designs that could potentially be used as ideas for our final design. These concepts incorporated several similarities from arm braces we had done research on previously. From there we began modifying our ideas so that they would better meet the requirements we had set as our standard. Concurrently, while designing and modifying these concepts, we were creating a potential materials list. This list was divided between each separate section of the brace (i.e. arm band, resistance mechanism etc.). Each section had its own list of potential materials that could be a viable solution for each segment. The building and modifying of the prototypes was a continuous process throughout every term.

Financially, every member of the team was awarded $150 for purchasing materials. In total, our team had approximately $600 to spend on building several prototypes and the final product. We began by being conservative in our budget, creating our first prototype with items such as cardboard so that we could save as much money as possible for the actual prototype in the future. An image of our first prototype can be seen in Figure 8. This prototype was made out of recycled cardboard, duct tape, ribbon and a few paperclips.

Figure 8 - Initial Prototype

For our second prototype, we bought relatively inexpensive materials that mimicked the future design and its properties. This prototype can be seen within Figure 9. It was made out of metal bars, a rubber o-ring, washers, a wing nut, and strips from a yoga mat.

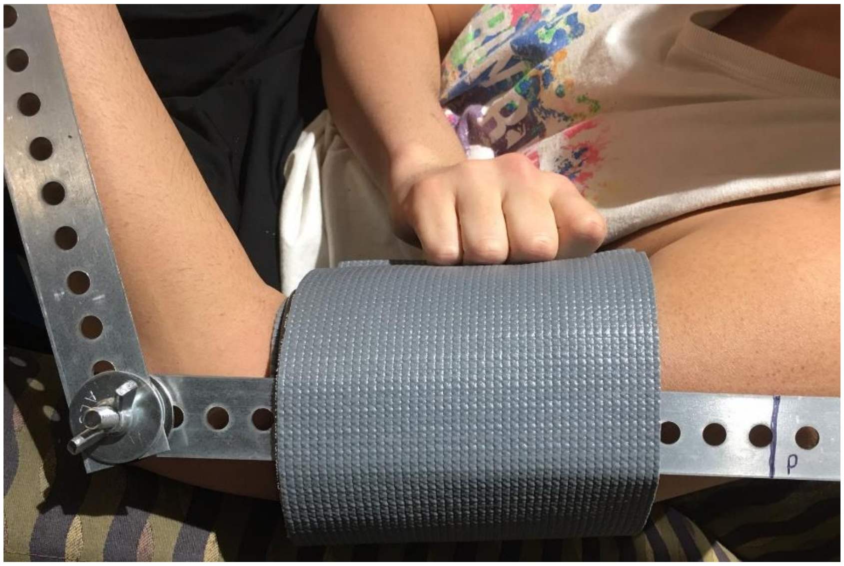

Figure 9 - Second Iteration of Prototype

Making this prototype allowed for us to better understand how our design would work with all of the components together. This therefore allowed us to begin troubleshooting any apparent issues and make corrections in the general mechanics of the prototype.

9: Design Requirements

There are six major components that play a factor in the brace's design requirements. These functional requirements are the reason why our team decided to make specific decisions for what would become our final product. Adjustability, accommodation, cost, materials, weight, and forces were the most pertinent to the brace design.

Adjustability is important in order to ensure that the brace can be utilized by anyone. This brace was created with adjustable arm bars that could fit sizes ranging from child to adult. The brace is able to be adjusted from an arm of 6 inches in length to an arm of 12 inches in length.

People who have ataxia struggle with movement, so the device needs to be lightweight. There are several different mechanisms to this design that play a key part in the overall product. The initial step was to put on a protective sleeve made out of cotton or polyester material. This alleviates any discomfort that could be caused by pieces of the brace that could come into contact with the skin while also holding the metal arm bars secure. The armbands are made from two iPod running bands to stay in place on the arm. Finally, the two bars that attach to the arm are a lightweight metal, and paired with the friction aspect in the joint, allow for the patient to start rebuilding muscle every time they make a movement with their arm. The design for this device is made for the specific movement of extension and flexion the arm muscles, and it must be able to withstand the forces put on it by the patient, as well as any weathering aspects that might occur.

We began brainstorming our preliminary designs starting early on in A term. It was important to understand the basic necessities needed for an arm brace. In order to accomplish this we began researching types of arm devices that could incorporate a friction component. These braces looked similar to slings or casts used to maintain a broken or sprained elbow. We began designing our preliminary sketches with these types of devices in mind. We knew that this brace could be used by a variety of people with ataxia; therefore it should incorporate a friction component in order to provide strength training to combat the spastic movements that are common with ataxia. It also needed to be able to support the weight of an arm while also being lightweight enough to be comfortable for the wearer. It had to be adjustable so that it could be used by a variety of people with different sized arms. We also wanted to include an adjustable friction component so that the force of the resistance could be adjusted based on the severity of the ataxia, as well as an adjustable length element. We established a list of functional requirements we deemed necessary. The following is a list of the functional requirements that we would later use to cross compare each design. The cross comparison table can be found in Appendix A.

Our first preliminary design was a basic arm device that utilized a therapy band in order to incorporate resistance. Our second design had the same arm device, but instead of a therapy band it utilized a wire based friction system, similar to the tightening of a ski boot. Our third design was a piston-based design that would create friction by incorporating an electric piston to cause friction. Our final major design was a strictly friction based system that used a foam gasket to create adjustable friction. These four initial designs all incorporated some type of resistance mechanism that could help the patient strengthen their muscles.

The first of these designs began by using a therapy band that wrapped around the outside of the arm. The idea behind it was that the therapy band could be interchangeable so the amount of resistance acting on the arm could also be interchangeable. The therapy band would reach from the top of the upper bicep and run along the arm, stopping at the wrist. It was designed with the patient in mind in regards to ease of use, adjustability of resistance, and easily replaceable components.

The second design was based off our original therapy band design, but instead of using a therapy band it utilized a wire system that could be tightened to increase or decrease resistance. Similar to the first design, the wire would run along the outside of the arm device and could be adjusted by the gasket at the center of the elbow.

The piston-based designed would utilize a hydraulic piston that would be able to support the patient in moving his or her arm by assisting his or her movements and would incorporate an electronic component.

Our final design was our friction-based design. This design had two separate armbands that would hold two adjustable metal bars together, connected by a foam gasket. This foam piece would be inserted between a washer and tightening mechanism allowing the resistance to be increased or decreased in both directions.

While compiling ideas for potential arm braces, we also devised a list of design requirements that any brace we made had to follow. For example, the end product had to be: safe for the user, easily fixable, lightweight, and have multifaceted adjustability. We compiled a list of 16 different requirements and weighted each category based on its necessity to make a usable end product. We then assigned each brace a number based on how well it could meet that requirement. The evaluation was based on a scale from 0 to 4 with 0 meaning the design did not meet the requirement and 4 meaning that the design fully met the requirement. From there we multiplied each weighing factor by the assigned value and then added up each brace's score to find a total score that we then could use to cross compare each brace in order to highlight the strengths and weakness of each brace.

One issue we encountered during the beginning of our preliminary design phase was that the piston-based design as well as the therapy band design could only apply resistance in one direction.

9.1 Therapy Band

The therapy band design was the first design that the team discussed. The highlight of this design was that the resistance could be changed based on the patient's needs. While the arm would be encapsulated in some sort of sleeve, the therapy band would run along the outside of the arm and provide resistance when the elbow was moved laterally outwards. This idea of an adjustable resistance mechanism carried through all of the designs we created. These therapy bands could be changed and replaced easily to increase or decrease the resistance. However, the resistance could only be applied in the outward direction, whereas we required that the resistance be applied in both the outward and inward direction. This idea incorporated an easily adjustable mechanism and could be easily interchangeable and we incorporated this idea throughout our other designs. However, since this brace only had resistance in one direction and our requirement was that it had to have resistance applied in both directions it would have to be discussed further to be applied.

9.2 Wire Adjust

Our second brace idea was very similar to the therapy band idea in that it ran along the outside of the arm and met in the middle at a mechanism that bound the two wires together and could pull them together to increase the resistance. This would streamline the process of increasing the resistance without having to remove any pieces of the brace (such as the bands of the previous brace). However in this design the wire would be hard to replace if damaged and had the potential to be easily broken if tightened passed its limit.

9.3 Piston

The piston-based design was very different from our first two designs. The idea behind it would be that it could aid a patient in moving his or her arm by providing an output motion based on the input of their arm movement and could increase and decrease the resistance manually without the need to turn a mechanism or exchange bands. This design relied heavily on our ability to design and program a machine that could accomplish this goal. This device would not be easily compactable, easy to replace, fix or be lightweight, which are several requirements that are necessary for this project design to be successful and would decrease the ability for the patient to use it easily.

9.4 Friction

Our friction based design has two metal bars that meet at the center gasket located at the elbow, and the length of the device can be adjusted due to the holes that run down the center of the two metal bars. At the gasket there is a piece of piping insulation foam that is compressed by two metal washers and a knob that can be used to tighten or loosen the pressure between washers, effectively adding an adjustable friction element. The two metal bars are attached to two separate IPod Running bands, allowing adjustability in arm size. The product is lightweight and has incorporated ideas from all of the previous designs. While using the cross comparison chart, the friction/gasket brace scored the highest and it allows for resistance to be applied in both directions.

9.5 Final Design

We decided to proceed with the friction/gasket design because it met all of the top 5 requirements with either a score of 3 or better and beat its next competitor by a significant margin. This prototype was favored due to the fact that we could control the amount of resistance applied to the arm in both directions. The following images are the CAD model that we designed in order to idealize our next prototype.

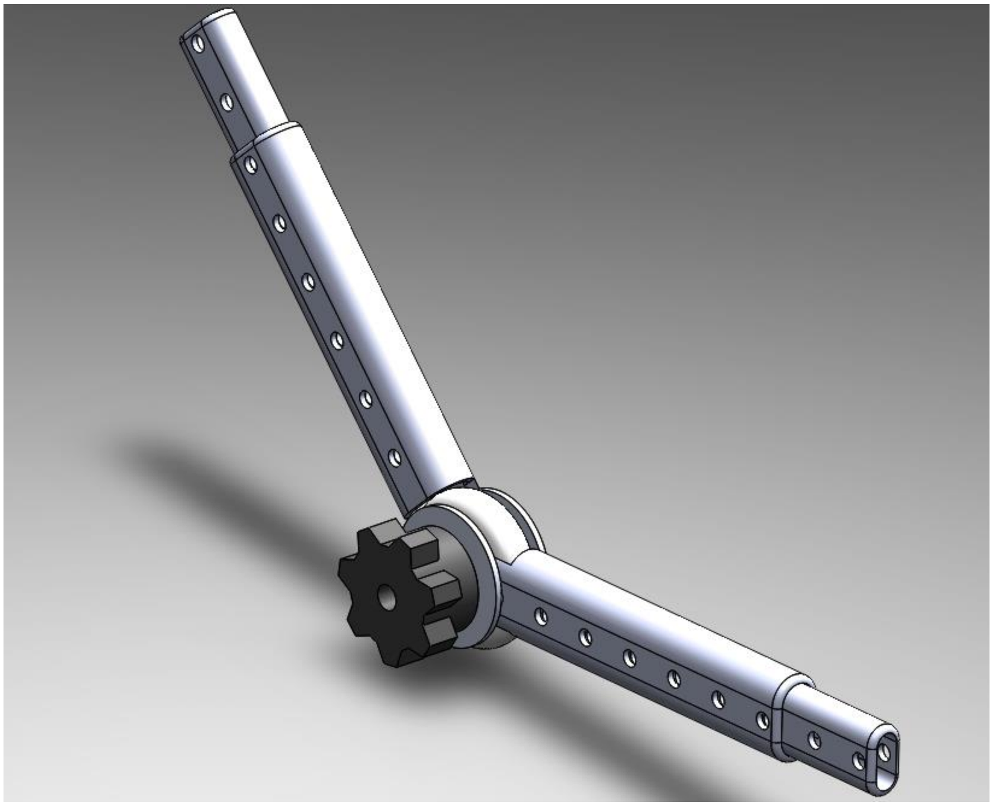

Figure 10 - Full view of device

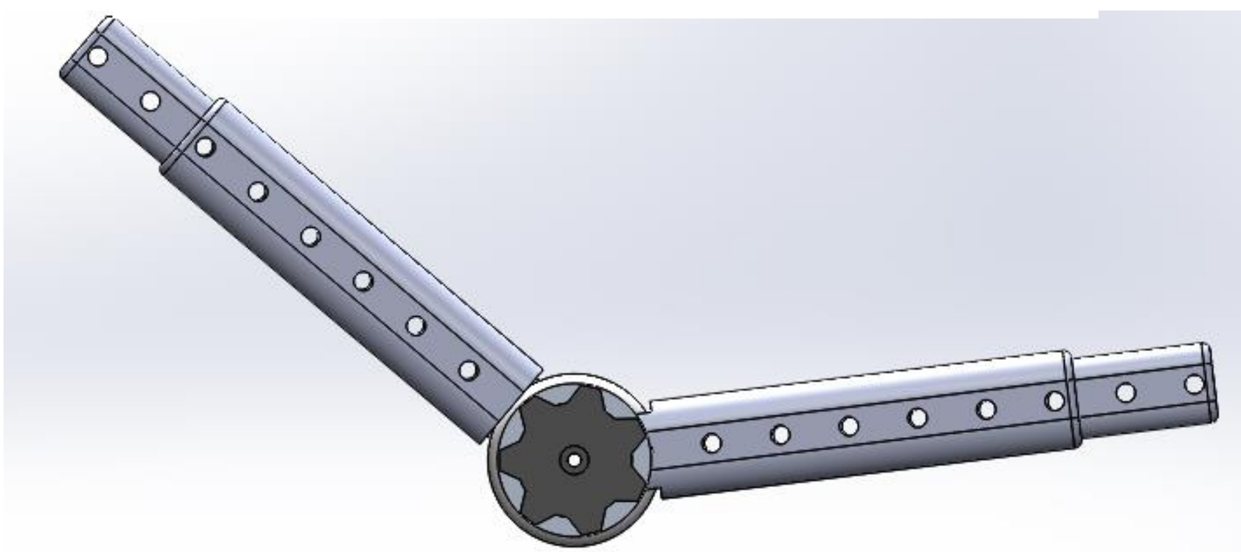

Figure 11 - Side view of device

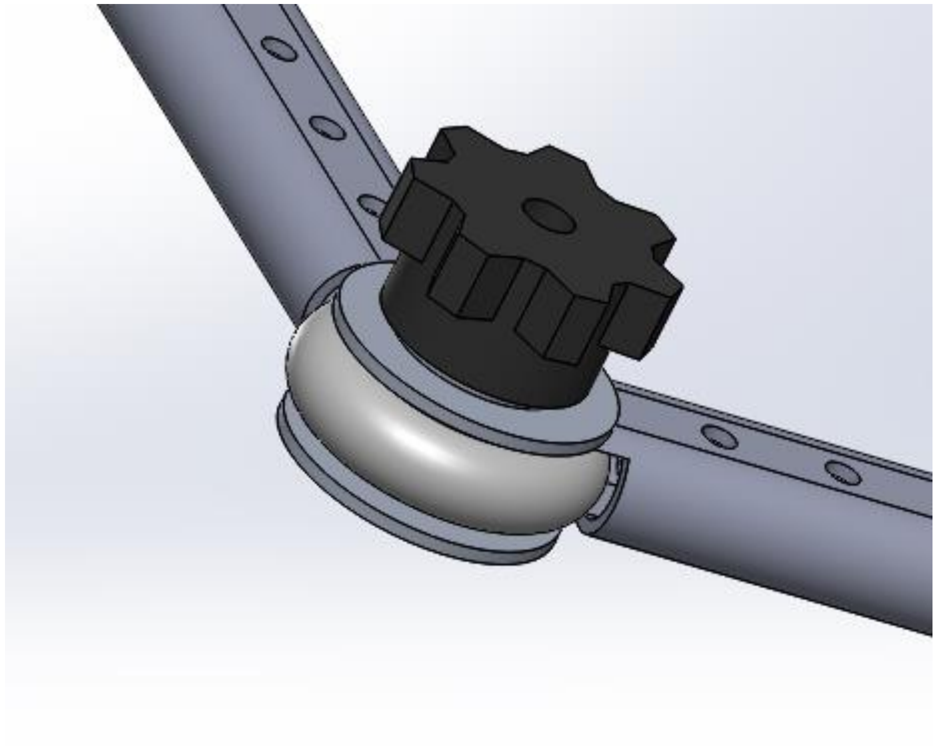

Figure 13 - Outer angle view of friction joint

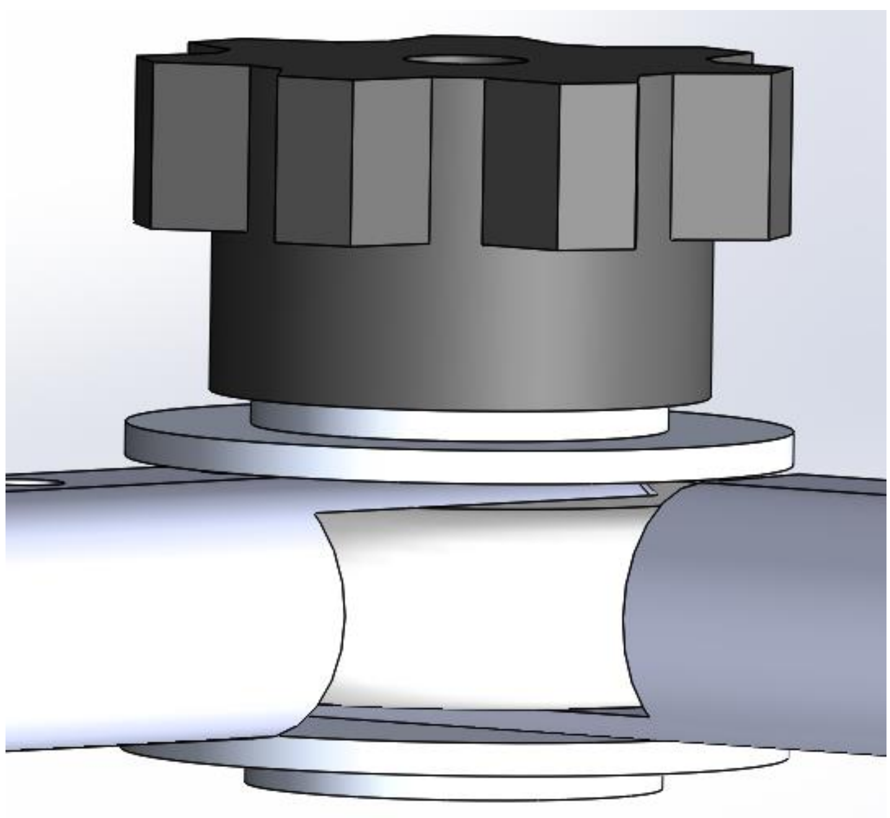

Figure 12 - Zoomed in inner portion of joint

9.6 Prototype

Figure 14 - Final Device being worn by Alex Powers

10: Design Verification and Performance Evaluation

10.1 Adjustability

One on the main requirements that was decided on was to ensure that the brace could be adjustable in several ways. We wanted the bicep section of the brace to be able to be adjusted from a length of 6 in to 12 in. This was accomplished through using bars with evenly spaced holes punched in it, which allows for the adjustability from 6 in to 12 in. The forearm section of the brace was intended to be able to be adjusted the same distance, and is accomplished through the same (hole-spaced) function as the bicep portion.

10.2 Materials/Replicability

All of the materials that were used in the building process of the brace were obtained at either a hardware store or another similarly accessible store. This allows for any of the materials used to be purchased if replacement parts are necessary. Additionally, this allows for even more customizability in the brace, ranging from an aesthetic change of color to different materials utilized is desired.

10.3 Weight

In order to ensure the feasibility for use of the device, one of the functional requirements was to keep the device under 5 lbs. This is easily measurable by using any form of commercial scale to measure the weight of the device. Since adjustability and adaptability are one of the major component requirements, there are a large range of possibilities for the potential weight. However, using the materials that our group suggests, the weight should only range between 0.5 and 2 lbs. (due to difference in size of straps, etc.)

10.4 Weathering/Durability

Another crucial component of our project is ensuring that the brace will stand up to the intended usage. All of the materials used in the project have high resistance to wear by themselves for their intended use, and none of the materials used will be undergoing stresses or forces that they are not designed to. The hole-punched bars that provide the adjustability and backbone of the brace are incredibly resilient to the directional bending and forces that they undergo during use in our brace.

11 Recommendations

Easier Manufacturability – Having the design be less complicated and easier to assemble would lend towards the device being able to be produced on a mass scale if desired. Additionally, the construction of the device would not lend itself to easy manufacturing, so having a design that could be assembled in a top-down fashion or something similar would make machine assembly viable.

Distinctive Settings – Having distinctive and standard settings would allow for a very visible change in friction applied to the user. These distinctive settings would ensure that the same amount of restrictive force could be applied via the brace every time it is used. This could be achieved through using a different kind of friction mechanism that has a smaller viable range of compression to apply friction.

One Fluid Piece – Having each of the arm bar pieces be one fluid piece would reduce the construction time of the design. This aids the ease of manufacturability, and also reduces stress points and possible pinch points in the design.

Enclosure for resistive joint – Designing an enclosed system for the resistive joint would reduce the possibility of having pinch points in the design. This enclosure could be made out of metal or a plastic polymer, and would also allow for the distinctive settings for friction that were suggested.

12: References

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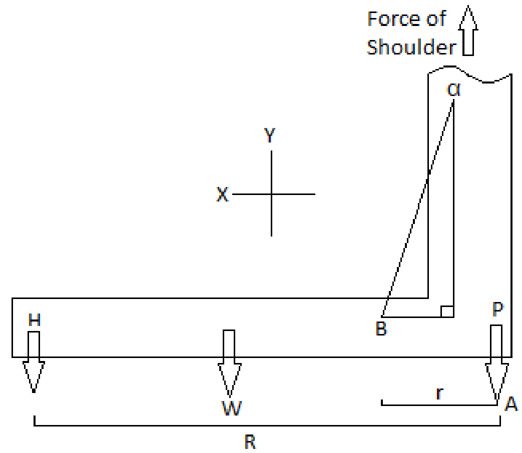
Appendix A – Cross Comparison

	Weighting Factor Scale 1-16 Scale 0-4	**Design #1: Friction Based**		**Design #2: Wire Adjust**		**Design #3: Therapy Bands**		**Design #4: Piston Based**	
Safe	16	3	48	3	48	3	48	2	32
Support at least one arm	15	4	60	4	60	4	60	4	60
Friction in multiple Directions	14	4	56	1	14	0	0	2	28
Adjustable Length	13	4	52	3	39	4	52	3	39
Adjustable Resistance	12	4	48	2	24	4	48	2	24
Weighs under 5 lbs	11	3	33	3	33	4	44	1	11
Skin contact points	10	3	30	3	30	3	30	3	30
Wear Resistant	9	3	27	2	18	3	27	2	18
Easily fixable	8	2	16	2	16	4	32	2	16
Durable	7	3	21	2	14	3	21	3	21
Workable by patient	6	2	12	3	18	4	24	2	12
At least 4 points of contact	5	4	20	4	20	4	20	4	20
Manufacturable	4	3	12	3	12	2	8	2	8
Compact	3	3	9	3	9	3	9	2	6
Inexpensive	2	2	4	3	6	4	8	2	4
Water resistant	1	2	2	3	3	3	3	2	2
Total			**450**		**364**		**434**		**331**

Appendix B – Calculations

The following calculations show the equations that are derived to calculate the force required to curl the arm at any angle.



$$\sum F_X = Bsin\alpha - P = 0$$

$$\sum F_Y = Bcos\alpha - H - W - A = 0$$

$$Bcos\alpha = H + W + A$$

$$\sum \tau = (H)(R) + (W)(\frac{R}{2}) - (Bcos\alpha)(r) = 0$$

$$(Bcos\alpha) = (H + \frac{W}{2})(\frac{R}{r})$$

$$B = (\frac{H+W}{2})(\frac{R}{rcos\alpha})$$

$$A = Bcos\alpha - H - W$$

$$= (H + \frac{W}{2})(\frac{R}{r}) - H - W$$

$$= (\frac{R}{r} - 1)H + (\frac{R}{2}r - 1)W$$

$$\varepsilon = \frac{\Delta L}{L_o} = \frac{L - L_o}{L_o}$$

F_X = Force in the X Direction
F_Y = Force in the Y Direction
B = Force of Bicep
α = Angle of Bicep
P = Point of rotation (Elbow Joint)
H = Weight of Hand
W = Weight of Forearm
A = Weight of Upper Arm
R = Distance between center of mass of hand and point of rotation
r = Distance between Bicep and point of rotation

L_O = 0.03175 m ΔL = 0.001905 m A = $\sigma = \frac{F}{A}$) = 0.000544543 m^2

ε = 0.06

$$\frac{\Delta L}{L_o} = \frac{\sigma}{E}$$

E ≅ 0.05 GPA under ideal conditions for Compressible Polyester Based Closed Cell Foam

$$0.06 = \frac{F/A}{0.05}$$

F = N =81.6145 N is the Normal Force under Ideal Conditions

$F_k = \mu_k N$ μ_K = 0.02

F_k = Kinetic Friction
μ_k = Kinetic Friction Coefficient
N = Normal Force

F_K ≃ 16.33629 N as a maximum amount of Kinetic Friction applied to the joint using a piece of foam that is 0.03175 m in thickness. If the thickness of the foam piece is increased, then the maximum force that can be applied to the joint will be increased, and if it is thinner, it will have a lower maximum. This force is added into the torque equation above, dictating the forces required to curl the arm.

F_k = Kinetic Friction
μ_k = Kinetic Friction Coefficient
N = Normal Force

Appendix C – Berg Balance Scale

Name: ______________________ **BERG BALANCE SCALE** Date: ____________

Rater: ______________________ 14-Item Long Form Original Version

1. SITTING TO STANDING
INSTRUCTIONS: Please stand up. Try not to use your hands for support.
(4) able to stand without using hands and stabilize independently
(3) able to stand independently using hands
(2) able to stand using hands after several tries
(1) needs minimal aid to stand or to stabilize
(0) needs moderate or maximal assist to stand

2. STANDING UNSUPPORTED
INSTRUCTIONS: Please stand for two minutes without holding.
(4) able to stand safely 2 minutes
(3) able to stand 2 minutes with supervision
(2) able to stand 30 seconds unsupported
(1) needs several tries to stand 30 seconds unsupported
(0) unable to stand 30 seconds unassisted If a subject is able to stand 2 minutes unsupported, score full points for sitting unsupported. Proceed to item #4.

3. SITTING WITH BACK UNSUPPORTED BUT FEET SUPPORTED ON FLOOR OR ON A STOOL
INSTRUCTIONS: Please sit with arms folded for 2 minutes.
(4) able to sit safely and securely 2 minutes
(3) able to sit 2 minutes under supervision
(2) able to sit 30 seconds
(1) able to sit 10 seconds
(0) unable to sit without support 10 seconds

4. STANDING TO SITTING
INSTRUCTIONS: Please sit down.
(4) sits safely with minimal use of hands
(3) controls descent by using hands
(2) uses back of legs against chair to control descent
(1) sits independently but has uncontrolled descent
(0) needs assistance to sit

5. TRANSFERS
INSTRUCTIONS: Arrange chairs(s) for a pivot transfer. Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests. You may use two chairs (one with and one without armrests) or a bed and a chair.
(4) able to transfer safely with minor use of hands
(3) able to transfer safely definite need of hands
(2) able to transfer with verbal cueing and/or supervision
(1) needs one person to assist
(0) needs two people to assist or supervise to be safe

6. STANDING UNSUPPORTED WITH EYES CLOSED
INSTRUCTIONS: Please close your eyes and stand still for 10 seconds.
(4) able to stand 10 seconds safely
(3) able to stand 10 seconds with supervision
(2) able to stand 3 seconds
(1) unable to keep eyes closed 3 seconds but stays steady
(0) needs help to keep from falling

7. STANDING UNSUPPORTED WITH FEET TOGETHER
INSTRUCTIONS: Place your feet together and stand without holding.
(4) able to place feet together independently and stand 1 minute safely
(3) able to place feet together independently and stand for 1 minute with supervision
(2) able to place feet together independently but unable to hold for 30 seconds
(1) needs help to attain position but able to stand 15 seconds feet together
(0) needs help to attain position and unable to hold for 15 seconds

( ) TOTAL SCORE (Maximum = 56) ,a person scoring below 45 is considered to be at risk for falling.

8. REACHING FORWARD WITH OUTSTRETCHED ARM WHILE STANDING
INSTRUCTIONS: Lift arm to 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the finger reaches while the subject is in the most forward lean position. When possible, ask subject to use both arms when reaching to avoid rotation of the trunk.).
(4) can reach forward confidently >25 cm (10 inches)
(3) can reach forward >12 cm safely (5 inches)
(2) can reach forward >5 cm safely (2 inches)
(1) reaches forward but needs supervision
(0) loses balance while trying/requires external support

9. PICK UP OBJECT FROM FLOOR FROM A STANDING POSITION
INSTRUCTIONS: Pick up shoe/slipper which is placed in front of your feet.
(4) able to pick up slipper safely and easily
(3) able to pick up slipper but needs supervision
(2) unable to pick up but reaches 2-5cm (1-2 inches) from slipper and keeps balance independently
(1) unable to pick up and needs supervision while trying
(0) unable to try/needs assist to keep from losing balance or falling

10. TURNING TO LOOK BEHIND OVER LEFT AND RIGHT SHOULDERS WHILE STANDING
INSTRUCTIONS: Turn to look directly behind you over toward left shoulder. Repeat to the right. Examiner may pick an object to look at directly behind the subject to encourage a better twist turn.
(4) looks behind from both sides and weight shifts well
(3) looks behind one side only other side shows less weight shift
(2) turns sideways only but maintains balance
(1) needs supervision when turning
(0) needs assist to keep from losing balance or falling

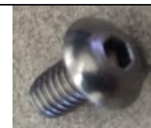
11. TURN 360 DEGREES
INSTRUCTIONS: Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.
(4) able to turn 360 degrees safely in 4 seconds or less
(3) able to turn 360 degrees safely one side only in 4 seconds or less
(2) able to turn 360 degrees safely but slowly
(1) needs close supervision or verbal cueing
(0) needs assistance while turning

12. PLACING ALTERNATE FOOT ON STEP OR STOOL WHILE STANDING UNSUPPORTED
INSTRUCTIONS: Place each foot alternately on the step/stool. Continue until each foot has touched the step/stool four times.
(4) able to stand independently and safely and complete 8 steps in 20 seconds
(3) able to stand independently and complete 8 steps >20 seconds
(2) able to complete 4 steps without aid with supervision
(1) able to complete >2 steps needs minimal assist
(0) needs assistance to keep from falling/unable to try

13. STANDING UNSUPPORTED ONE FOOT IN FRONT
INSTRUCTIONS: (DEMONSTRATE TO SUBJECT) Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot. (To score 3 points, the length of the step should exceed the length of the other foot and the width of the stance should approximate the subject's normal stride width).
(4) able to place foot tandem independently and hold 30 seconds
(3) able to place foot ahead of other independently and hold 30 seconds
(2) able to take small step independently and hold 30 seconds
(1) needs help to step but can hold 15 seconds
(0) loses balance while stepping or standing

14. STANDING ON ONE LEG
INSTRUCTIONS: Stand on one leg as long as you can without holding.
(4) able to lift leg independently and hold >10 seconds
(3) able to lift leg independently and hold 5-10 seconds
(2) able to lift leg independently and hold = or >3 seconds
(1) tries to lift leg unable to hold 3 seconds but remains standing independently
(0) unable to try or needs assist to prevent fall

Appendix D - Assembly of Device

Part Name	Quantity	Cost	Image
Outer Arm Bar	2	$6.70/each	
Inner Arm Bar	2	$5/each	
Arm Bar Bolt	2	$0.72/each	
Washer with Bolt	1	$0.60	
Washers	2	$0.48/each	
Resistance Styrofoam	1	$0.97	
Adjustable Knob	1	$3.28	

Adjustable Armbands	2	$8/each	
Compression Sleeve	1	$6	

1. Remove any clothing from the arm that the device is going to be placed on. Slide on arm compression sleeve so that it rests high enough on the arm and does not cover the hand.
2. Place the bolt and washer with the bolt cap resting on the table and the threaded portion in the air.
3. Place the side with the extended metal portion onto the threaded bolt.
4. Next, place the resistance Styrofoam ring onto the bolt.
5. Place the second washer onto the blot along with the second arm bar extension
6. To finish the joint device, screw on the adjustable knob until desired resistance is reached
7. Next, slide both metal bars into their respective arm bands making sure that the holes in the plastic, metal, and delrin all line up
8. Thread screw in desired location have device has been adjusted to appropriate length
9. Finally, attach each armband to the correct arm, one at the upper arm and one on the forearm and tighten using the Velcro straps.