X-Chair: Autonomous Wheelchair Restraint Adaptations

BME 400

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Abstract

A large number wheelchair users are currently unable to take advantage of the benefits of movement due to various challenges they encounter. Moving the body has many benefits for almost all major organs and is beneficial for a number of bodily functions. Neuromuscular conditions inhibit the straightening of joints, limiting the overall mobility of the patient, which forces them to stay in a seated position for the majority of the day. The cost of hiring a CNA or other licensed physical therapist is expensive and is typically not covered by health insurance for those affected by a permanent disability. The client, who has been diagnosed with Type II Spinal Muscular Atrophy (SMA), has requested a device to enable autonomous body movements to further prevent atrophy of his muscles and aid in bodily functions. Through research and analysis of existing devices, the team determined there were no compatible existing devices, and have developed four plausible preliminary designs. These designs were evaluated using three design matrices and ascertained that the future design will focus on adapting the client's existing standing wheelchair using the Boa system technique. This design will allow the client to access and operate his standing wheelchair autonomously by securing himself with the newly implemented chest and legs restraints. The Boa system will be automated to guarantee independent usage by the client and improve the overall usability.

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I. Introduction

a. Problem Statement

A large number wheelchair users are currently unable to take advantage of the benefits of movement due to various movement challenges they encounter. Moving the body has many benefits for the brain, muscles, bones, joints, intestines, heart, lungs and other organs. Movement is also beneficial for a number of bodily functions such as blood flow, digestion, muscle strength, and bone health. Neuromuscular conditions inhibit the straightening of joints, limiting the overall mobility of the patient, which forces them to stay in a seated position for the majority of the day. The cost of hiring a CNA or licensed physical therapist is quite expensive and usually is not covered by health insurance for those affected by a permanent disability. The goal of this project is to develop a device that enables wheelchair users to move in various positions, allowing them to strengthen muscles, aid in bodily functions, and help reduce their current movement limitations.

b. Impact

There is an immense amount of people across the United States and the world that need to utilize a wheelchair on a daily basis, with approximately 75 million wheelchair users worldwide and 3.3 million wheelchair users in the United States [1, 2]. Similar to the client, many wheelchair users could benefit from a device that would allow them to move themselves in previously unattainable positions to aid in blood flow, digestion, physical health, and mental health. Helping provide the opportunity to move in positions such as prone or vertical, positions that many non-disabled people take for granted, could help immensely in improving the lives of those affected by diseases that require them to utilize a wheelchair.

c. Existing Devices

While there are no devices to aid in full body movement for SMA patients, there are many devices and working systems that are available that can be altered or used to create a more encompassing device that can be widely used.

Inversion tables are an exercise machine that enables users to relieve pressure from their spine by inverting their body, along with strengthening core muscles. The table utilizes feet restraints allowing the user to place their feet between two pads, securing them safely to the table. The user is then able to invert his/her body for a period of time, alleviating pressure on the spine and providing an adequate stretch. The more that an inversion table is used by an individual, the longer the user can remain inverted, but they generally should not exceed an inversion period of 15 minutes, even with experience [3]. There are a limited number of wheelchair user adapted inversion tables, but these inversion tables require a large amount of upper body strength to operate safely. The adapted inversion tables have a strap attached to the base of the table from the head of the inversion table, limiting the rotation of the table to horizontal at rest. This allows the user to enter the table from their wheelchair, but this requires a large amount of upper body strength and has the potential to accidentally invert if the user's center of mass is too high up the table.

Figure 1: Wheelchair adapted inversion table with a strap to hold the table horizontal at rest [4].

Vibration plates and other vibration devices are mainly used to treat sore muscles, however they also have numerous other positive impacts including the ability to increase bone density, increase muscle mass, improve circulation, and reduce joint and back pain [5]. By using a whole body vibration device for 15 minutes a day, multiple days a week, users can experience enhanced blood flow, decreased stress, along with other positive body benefits [6]. Full body vibration plates are also accessible for wheelchair users. By placing the users feet on a vibration plate for up to 10 minutes, this can aid in the circulation to lower extremities as well as enhance the flow of lymph fluids from the ankles towards the heart [7]. In addition to this, by placing the elbows on the knees during vibration the neck and shoulders will be relieved of pain and circulation of the upper body will improve [7].

Blood pressure cuffs are composed of an inflatable rubber bladder, a sleeve for the rubber bladder, and an attached air pump. The rubber bladder is inflated by the air pump, which is automatic or manual, to expand and tighten around the patient's arm. When tightened enough, the pressure cuff occludes the brachial artery, but below that threshold the rubber bladder provides support to the arm which it surrounds. The inflatable cuff concept could be implemented to provide a comfortable restraint that is adjustable by varying the level of inflation within the pressure cuffs. The cuffs would need to be inflated enough to provide support, but not occlude the vascular system of the client during operation.

The Boa system provides a mechanism for easy tightening of laces/restraints. It utilizes a stainless steel wire along with a circular piece that is used to tighten and loosen the wire "laces". The Boa system is currently used for a variety of applications, including a heavy duty version for snowboarding and bulky equipment, lightweight and easily adjustable versions for running and cycling shoes, as well as another version that allows use in medical equipment such as braces and prosthetics. The system works by shortening the laces when the circular button is spun clockwise. As a result, the laces become tighter around the area they are wrapped around. For the team's purposes, this system would be implemented in the tightening of the leg restraint and the chest restraint for the client. This allows for a simple mechanism that allows the client to be able to secure the restraints by himself.

Roller coaster restraints are used to hold people in rides that go upwards of 50 miles per hour and flip and roll upside down. These restraint systems are well known and have already been demonstrated as being safe during operation. One particular roller coaster, SUPERMAN: Ultimate Flight, which can be seen in Figure 2, uses a linked restraint system. As the over-the-shoulder shoulder restraint locks into place, leg restraints also engage to hold the legs back during the ride. This synchronous system would benefit the user, as he/she would only need to worry about tightening the upper restraint. Although this idea has the potential to work, it may get in the way of the client as he transfers into the wheelchair. The system must also be integrated with the client's wheelchair.

Figure 2: SUPERMAN: Ultimate flight roller coaster ride [8]

II. Background

a. Research

Spinal Muscular Atrophy, otherwise known as SMA, is a genetic disease that affects voluntary muscle movement. The name “spinal muscular” stems from the fact that most voluntary muscle movement is controlled by nerves in the spinal cord. “Atrophy” is the progressice decline or shrinkage of the muscles as a result of them not remaining active. SMA is caused by a deficiency of the motor neuron protein called SMN (survival of motor neurons) which affects the motor neurons and muscle cells. Oftentimes the severity of SMA in patients is correlated with the age of onset. The age of onset is correlated with SMN proteins. There are three main types of SMN related SMA. Type I is the most severe with the earliest age of onset being at birth . Usually this group of patients only live several years. A ventilator and feeding tube may be required due to declined respiratory and swallowing functions. Type II SMA can usually be seen in children between the ages of 8 to 16 months old. The child can typically sit without support. However, their proximal muscles are affected much sooner than distal muscles. The thighs, for example, become weaker before

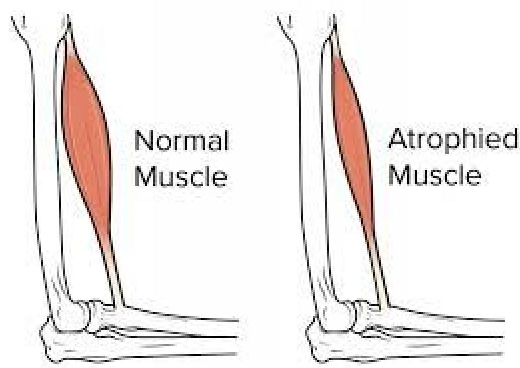

Figure [3]: Atrophied vs Normal Muscle [10]

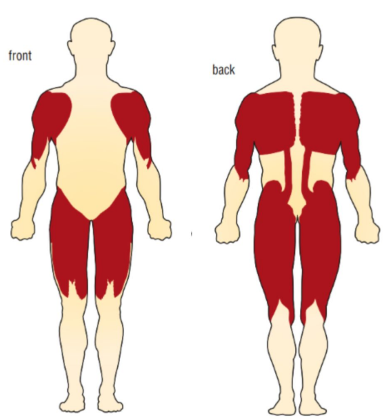

Figure [4]: The red regions are the proximal muscles which are affected first in patients with SMA [9].

the lower legs and feet. Legs generally weaken before the arms; hands remain the strongest. Children can benefit from physical therapy, braces, and a variety of aids. Type III is the less severe with the latest age of onset being after 18 months or the child has taken at least 5 independent steps. Many can walk until their 30s or 40s, although some may stop walking in their teens. This group may use canes or walkers, needing a wheelchair for longer distances. Some professionals believe that Type IV SMA exists, which begins in adulthood, and has some of the lesser Type III traits. SMN related SMA genetically affects chromosome 5. Non-SMN related SMA has a wide range of severities or effects. For example, the most distal parts of the body like the hands and feet could be targeted first. Patients with SMA often develop a curvature in the spine as a child that can lead to scoliosis. The child usually has to undergo spinal fusion surgery to fix the problem. Respiratory muscle weakness and swallowing muscle weakness, may also be experienced presenting great danger [9].

There are multiple ways to get tested and diagnosed with SMA. The first step is a physical examination where the family history would be provided. Blood work should also be taken. High creatine kinase (CK) enzyme indicates muscle damage. Further genetic testing can be taken by family members who also get blood work. Occasionally a muscle biopsy may be recommended for further analysis. An electromyogram (EMG) can also be performed to see the speed at which nerves respond to signals [9].

Exercising can help to improve range of motion, prevent contractures, strengthen muscles, maintain swallowing and respiratory muscles, strengthen posture, allow for greater blood circulation, and provide an overall benefit to the person's mental well-being [11]. The extent to which an SMA patient can exercise is dependent on age, developmental stage, and neuromuscular involvement [12]. While aerobic exercise has evidence proving it to have a positive impact on patients, there is a lack of research indicating a positive impact as a result of strength training. The phenomena, "vicious circle of inactivity", is when a patient experiences loss of muscle strength, leading to inactivity, which deteriorates cardiovascular health and increases fatigue. This leads to more inactivity, leading to further loss of muscle strength [13]. Therapeutic exercise in SMA is used to improve function, range of motion, independence, and overall quality of life [14]. Functional exercise is the performance of movements that one would like to accomplish throughout the day. Rolling, reaching, and sitting are all functions that can help improve daily activities. Range of motion is movement and flexibility of the joints. ROM is maintained through stretching and without stretching, these muscles get tight. When the tightness becomes permanent, this is called a contracture. Contractures can prevent normal movement and increase discomfort. Weight bearing is also beneficial for muscles and bones. Standing can improve bone strength, respiratory, and bowel functions. Devices are used to help a person achieve a standing position. Some standing aids help a person lie on their belly or their backs; these are called the prone position and the supine position respectively. Also proven to be beneficial is water therapy. Water therapy allows for your body to be lighter and easier to move due to buoyancy in the water [12].

b. Client Information

The client, Keith Wanta, works as a senior programmer analyst in the Biostatistics and Medical Informatics Department at the UW - Madison School of Medicine and Public Health. Keith has been phenotypically diagnosed with Type II SMA and genetically diagnosed with

Type III. He has been unable to walk throughout his life, and has used a wheelchair throughout the majority of his life. The client has approached the team in hopes a solution for the problem can be found to help make his life easier. In all facets of the design, autonomy is most important to the client. The ability to independently achieve the standing position is the task the team looked into this semester.

c. Design Specifications

The device will be used by one individual on a daily basis, multiple times a day. The device must be in its active position during the duration of operation, for up to 8 hours at a time. The device will need to prevent the user from being ejected out of the wheelchair when enduring non-flat surfaces, too fast of acceleration, and abrupt stops. The electrical components must not shock the user, and the device must have a manual override to prevent the user from being stuck in the chair. The mechanical restraints cannot injure the user while entering his/her position, and the leg restraints cannot apply an excessive force on the user while in the standing position. This device must function for a minimum of 3-5 years with potential daily use from the end user. The device must be stored in a dry environment to mitigate damage of the electrical components. The device must not impede the operation of the wheelchair by the user. The restraints must provide a comfortable and secure hold on the user during operation. The device's appearance must not stand out from the wheelchair it is attached to in order to be indistinguishable from the wheelchair.

III. Preliminary Designs

a. The Inversion Table

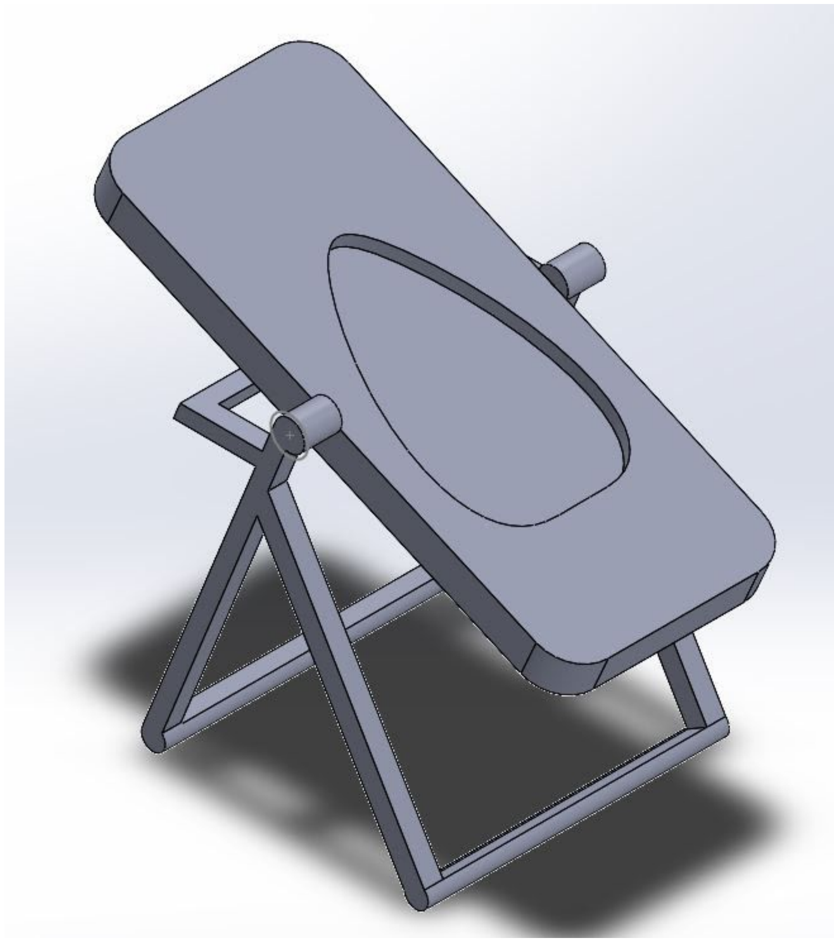

Figure 5: SOLIDWORKS model of the inversion table preliminary design

This design would be motorized to allow controlled rotation during operation and would be controlled by the user with a controller. The controller would be the user input to a microcontroller and would control the high torque motor used to rotate the table. As of now, the team is unsure if independent operation would be safe for the user, and has decided that a second person would be required to assist in applying the restraints and ensuring the user is safe during device operation. To allow the device to remain horizontal for entry, a locking mechanism would be engaged, and the table would rest on the rear horizontal support while the user enters. There would be an ergonomic indent in the chair that would fit the figure of the client to help support the client and increase the comfort during operation. The user would be secured in using a series of straps that would go across his/her body and tighten with the table to allow the user to safely rotate to a prone postition. The horizontal support bar prevents the table from rotating further than the prone position as well as support the table while the user enters the device. The frame would be rigid and arranged to ensure the table is stable while rotation occurs.

b. The Pressure Cuff System

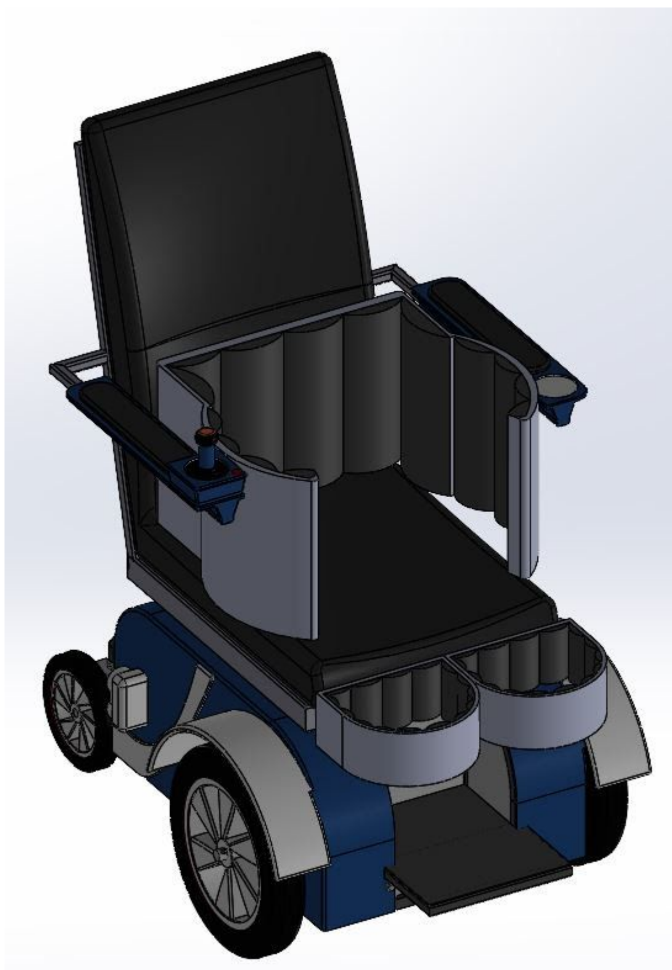

Figure 6: SOLIDWORKS model of the pressure cuff system preliminary design

This design incorporates pressure cuffs on both the leg restraints and the chest restraints to provide comfort and security for the user. The restraints would act similar to blood pressure cuffs and would inflate via a series of connected rubber bladders to various pressures. The leg restraints would be mounted to the wheelchair using the existing peghole for the current leg restraints to allow them to be removable and alleviate the need for permanent mounting on the wheelchair. The two leg restraints would be mounted onto a bar that would fit in the peghole, but each restraint would be completely enclosed, similar to how pictured in Figure 6 above. The restraints would only encompass a portion of the lower leg, from slightly below the knee to below the middle of the lower leg, and would be large enough the user could lower his/her entire foot through the opening while deflated for ease of use. The chest restraint would be secured to the chair using a strap that would encompass the back of the chair and would fit through the rear of the chest restraint. The restraint would be able to open to allow the client to enter the wheelchair and then would close via tightening a strap across the restraint. Due to the maximum angle of standing the client can reach within his wheelchair, the chest restraint will not have to bear as robust a load as the leg restraints and is more in place for added comfort and support during operation of the chair. The system would inflate with a portable air compressor that would be secured to the chair, and would be controlled by a control panel located within arms reach of the user. The inflation and deflation would be controlled by the control panel which would be connected to a microcontroller to allow variability in the level of inflation the user would like.

c. The Roller Coaster System

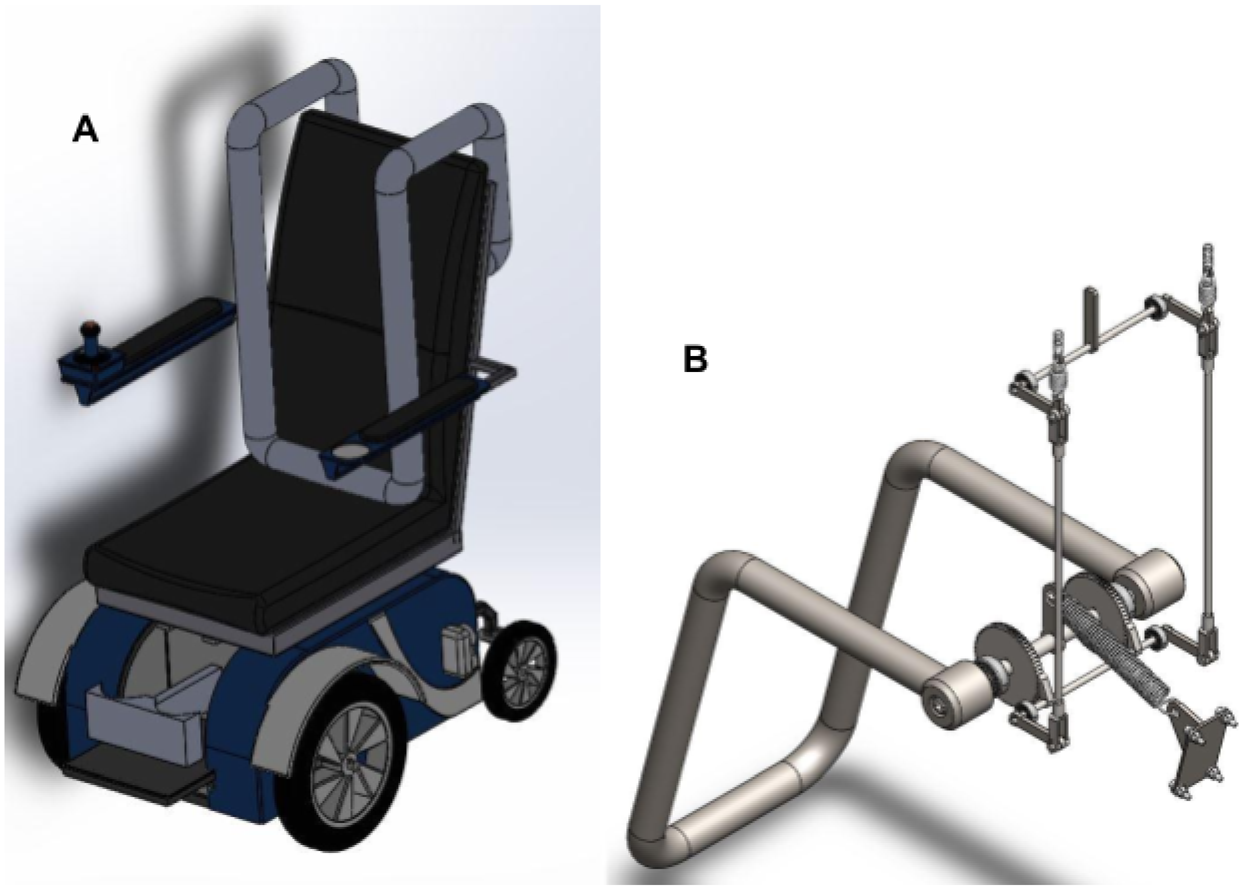

Figure 7: A) SOLIDWORKS model of the roller coaster system preliminary design. **B)** Ratchet system similar to what the chest restraint would utilize [15].

The roller coaster system consists of a system that is similar to the restraints on the SUPERMAN: Ultimate Flight ride at Six Flags Great America. As the over-the-shoulder restraint is pulled down tight to the user's body, the leg restraints would also fold out from the middle and over the legs to prevent him/her from falling away from the chair. This synchronous, linked system would create a much easier restraint system for the user, as he/she would only need to worry about the upper restraint. The chest restraint would use a locking ratchet mechanism similar to the one shown in Figure 7B above. A lever would release the ratchet mechanism, and the spring-loaded system would return to the chest restraint to resting position above the user. The leg restraints would also return flat against the bar protruding from in between the user's legs. This is a simple, well known system that is trusted on high intensity rides and attractions.

d. The Boa System

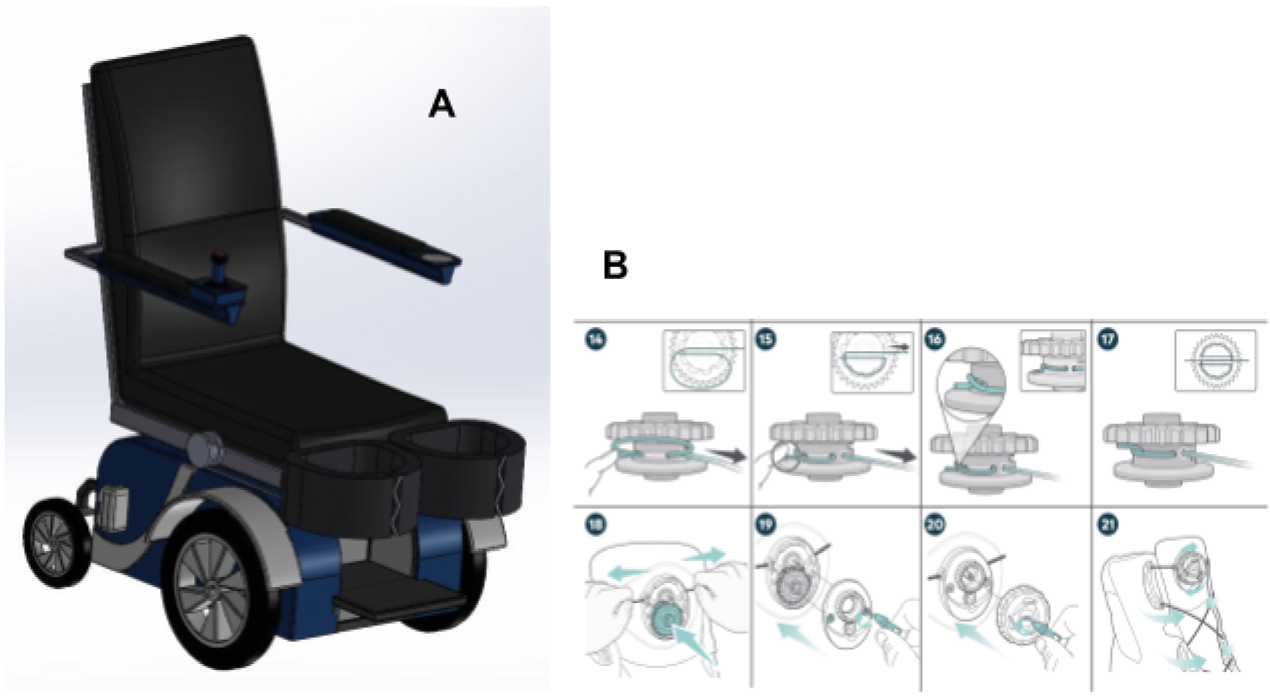

Figure 8: A) SOLIDWORKS model of the boa system preliminary design. **B)** Example of the Boa lacing mechanism [16]

This system would utilize the already existing Boa lacing system. As explained in the existing devices section, the Boa lacing system is made up of a small button mechanism and closed loop of wire. As the button is turned clockwise, it cinches and shortens the wires, tightening the loop. To loosen the system, the button is pulled up, and the tension in the wires is released. This button mechanism will be within arms reach of the user on the wheelchair, and he/she can tighten the restraints to the desired setting. In a similar manner to the pressure cuff design, the leg restraints would be mounted to the wheelchair using the existing peghole by being mounted onto a bar that would fit in the peghole. Each restraint would be completely enclosed, but the Boa system would be connected between the two restraints for ease of use. The restraints would only encompass a portion of the lower leg, from slightly below the knee to below the middle of the lower leg. While the Boa system is completely released, the gap in the restraint would be large enough the user could lower his/her entire foot through. In order to acclimate to SMA patients with less dexterity and strength, a lever will be added to the button mechanism to give the user extra leverage when turning the mechanism.

IV. Preliminary Design Evaluation

a. Design Matrices

Table 1: Design matrix comparing a standing wheelchair adaptation and inversion table against the following criteria.

Design Criteria	Standing Wheelchair Adaptation 	Inversion Table 
Safety (25)	20	15
Independence/Autonomy (20)	20	4
Ease of use (15)	12	6
Cost (15)	12	3
Comfort (15)	12	9
Stability(10)	8	6
Total (100)	84	43

a. Justification of Criteria

The first design matrix compares the idea of a standing wheelchair adaptation to the stand alone inversion table design.

Safety: The primary objective of this design is to create safe space for a user to be able to move/stand. For this reason, safety was weighted as the highest priority. The inversion table is a stand alone device that will be flipping the user upside down while only being held by restraint straps. This puts the user in a higher risk of injury. The standing wheelchair adaptation is using a standing wheelchair which is already built safely for the user. The adaptations to the wheelchair will be small, so the wheelchair should still be relatively safe. For this reason, the standing wheelchair adaptation was thought to be more safe.

Independence/Autonomy: One of the client's biggest requirements was that this design be usable by him independently, so independence and autonomy were weighted the second highest. With the complexities of the inversion table design, the team thought the user may need a second person to help set restraints and ensure the user is safe while using the design. The client is unable to use the standing function of his standing wheelchair by himself, but a standing wheelchair adaptation, such as a restraint system, will give him that option. Therefore, the standing wheelchair adaptation was graded higher than the inversion table.

Ease of Use: SMA patients have limited dexterity and strength, and because of this, the design must be easy to use. An adaptation on a wheelchair the user is already comfortable using will be much more comprehensive than a new, stand alone device such as the inversion table. For this reason, the standing wheelchair adaptation scored much higher than the inversion table.

Cost: The client gave the team a budget of approximately $2000 to work with. This is a number the team tried to stay under as far as possible. Therefore, a stand alone device that uses high torque motors and a microcontroller to control movement is relatively expensive compared to an addition to a standing wheelchair. A rough estimate of the cost of the inversion table ran up to approximately $720, compared to an adaptation which, at most, cost less than $500. These are only estimates, however the standing wheelchair adaptation is estimated to cost less and therefore, received a higher score.

Comfort: This device will be used multiple times throughout the day for extended periods and comfort is necessary for the user. The inversion table will use an ergonomic padding that will fit around the user. However, when inverted, the full weight of the user will be on the straps across his/her body which could become uncomfortable. The standing wheelchair is already designed for the user to be in for multiple hours at a time. The added restraints will have padding to ensure the user is not uncomfortable while tightening the restraints. Therefore, the standing wheelchair adaptation and inversion table were scored a 12 and 9 respectively, with the standing wheelchair adaptation slightly higher. Neither received a full score.

Stability: Stability refers to the ability of the design to fix the user firmly to the device. Neither design was thought to be perfect, however, the wheelchair adaptation was graded slightly higher due to the fact that it is made for a user and the positions the user will be in. The inversion table idea is putting the user in a different position than the original idea was designed for which could create stability issues.

Table 2: Design matrix comparing the three proposed systems to implement for a chest area restraint against the following criteria.

Design Criteria- Chest Restraint	Boa System 	Pressure Cuff 	Roller Coaster Harness 
Safety (25)	25	20	25
Ease of Implementation (20)	20	16	12
Ease of use (15)	15	12	15
Cost (15)	15	12	6
Comfort (15)	12	15	9
Stability(10)	10	10	10
Total (100)	97	85	77

b. Justification of Criteria

The second design matrix evaluates the wheelchair adaptation designs being implemented as chest restraints.

Safety: The number one priority for this project is to design a system that can be autonomously used by the client in a safe manner. Therefore, the team ranked safety as the highest priority as any aspect of the design that puts the client at risk will not allow for autonomous use, as well as put the client in harm's way. The Boa system and the roller coaster harness earned the highest ratings in terms of safety because the Boa system is already used in heavy duty, high force and impact situations such as snowboarding. In terms of the roller coaster harness, the restraint provided by this is well known and used widely for the purposes of restraining people from flying out of a roller coaster, which exhibits a wide array of forces in all directions, and the design of such a restraint accounts for all of these factors. Therefore, this system provides ample safety for the client.

Ease of implementation: Ease of implementation refers to the team's ability to implement the design and accounts for the necessary fabrication steps. A maximum rating means that the team has a good conceptual idea of how that system would be implemented into the final design, and the design is well within the team's ability to fabricate. The Boa system received a maximum score for this category because the team found detailed steps of how to put together a system, and overall it is a simplistic design that involves force of tension in stainless steel wires. In terms of the roller coaster system, this earned the lowest score because this system is the most difficult to implement in regards to the complexity of the fabrication process and the machining steps required to build the design.

Ease of use: This design matrix criterion refers to the client's ability to easily use the design for its intended purpose. The Boa system and roller coaster harness earned the maximum scores in this category. The Boa system implementation allows the client to tighten the chest restraint using the circular button. In terms of the roller coaster system, this criterion was evaluated with the thought that the client would reach up to pull the harness over his chest, similar to what is done by roller coaster riders. However, the team was able to meet with the client in person after the design matrix had already been evaluated, and the team got a better understanding of the client's limitations after the meeting. The team recognized that it would be nearly impossible for the client to be able to reach above the shoulders to pull the harness down. As a result, the team would need to implement an electrical component that does this at the press of a button. This does not change the ease of use rating for the design, as this new implementation would account for the client simply pressing a button to bring the chest restraint down, and also pressing a button to release the restraint when ready to get out of the standing wheelchair.

Cost: Cost is an important factor to consider as the client has provided the team with a budget of $2000. The Boa system earned the maximum rating for cost because the component pieces to put together the Boa system are relatively cheap with the following cost breakdown: Boa components $10, nylon webbing $27, padding $10. These are the requirements for the chest constraint, and for the leg constraint the only additional cost would be a fracture boot for $55. Overall, these components in total are well within the budget and allow for extra components to be ordered for the purposes of testing. The pressure cuff system received a slightly lower score, as this system requires additional components that are at a higher cost. The roller coaster design earned the lowest rating for cost, as the components are expected to be the most expensive, as they must be high quality metal pieces.

Comfort: The device must be comfortable for the client to use because it may be used numerous times throughout the day. The pressure cuff earned the highest rating because of the slight variability that is inherent to the design. That variability allows for the client to be set the inflation of the rubber bladders to the most comfortable setting. The other designs ranked slightly lower due to the lesser ability to customize the fit around the client.

Stability: This design criterion refers to the design's ability to fix the client firmly to the standing wheelchair. All 3 categories earned the maximum rating for this category because they are all building off of the standing wheelchair, and no individual design provides an advantage over the others.

Table 3: Design matrix comparing the three proposed systems to implement for a chest area restraint against the following criteria.

Design Criteria- Leg Restraints	Boa System 	Pressure Cuff 	Roller Coaster Harness 
Safety (25)	25	20	25
Ease of Implementation (20)	20	16	12
Ease of use (15)	9	9	12
Cost (15)	15	15	6
Comfort (15)	12	15	12
Stability (10)	10	8	10
Total (100)	91	83	77

c. Justification of Criteria

The third design matrix evaluates the wheelchair adaptation designs being implemented as leg restraints.

Safety: Safety is the most important criteria for the client, as the device must be operable safely and autonomously by the client. The Boa system and roller coaster designs earned the highest rating for the safety category, as they provide a restraint mechanism that has proved to be sustainable in high force and high impact situations that go beyond the forces and impact that the final design will encounter.

Ease of implementation: The Boa system earned the highest rating out of the designs for this criterion because of its simplistic design and existing instructions on how to implement the device. The roller coaster design provides the most difficult implementation, as it requires the leg restraints to be integrated with the overhead restraint. This ensures the client does not need any additional controlling to trigger the leg restraint to come into place other than bringing the overhead restraint into position.

Ease of use: The roller coaster system won the highest rating in this category because it does not require the client to do anything to put it into place; this will automatically happen as the chest restraint is brought into position. The Boa system requires the client to either bend down to tighten the boa system, or use a lever attached to a system that brings the cable up to the client's reach to tighten it. Either way, this is more than what is required for the roller coaster system.

Cost: The Boa system is the cheapest design as it requires the cheapest components. The pressure cuff requires additional components that are slightly more expensive than the Boa system. The roller coaster system requires the most expensive components, and thus earned the lowest score of the 3 designs.

Comfort: The pressure cuff system provides the highest level of comfort as it would allow the client to customize the level of inflation of the rubber bladders so that it is as comfortable. The other systems earned lower scores due to the lack of customization in comparison to the pressure cuff system.

Stability: Both the roller coaster system and the Boa system earned the maximum scores for this category as both are able to fix the user to the chair very well and pose no risks in doing so successfully. The ability to customize the pressure of the restraint leaves some lack in stability for the pressure cuff system resulting in it earning a lower score than the other two systems.

b. Proposed Final Design

Figure 9: SOLIDWORKS model of the proposed final design using the Boa system.

Following the evaluation of each design with the design matrices, the team determined that the Boa system would be the proposed final design for the design project. The Boa system performed excellently across all of the design matrices, winning or tying five of the six criteria for the chest restraint and winning or tying four of the six criteria for the leg restraints. Following an in person meeting with the client, the proposed final design will need to be heavily adjusted from the preliminary Boa system. The Boa system may not be a viable design due to the limited number of attachment locations on the client's wheelchair. The client also expressed that he does not want the chest support to remain tight during operation, as the existing device has a decent gap present from the client to the chest restraint. The client also expressed that he does not have the dexterity capabilities to attach any harnesses or close clasps manually, so the device would need to be motorized. The system would also need to essentially pivot around the client to allow entry and exiting of the wheelchair in a convenient and safe manner. To automate the Boa system, a motor will control the gear system, which will allow the client to tighten and release the Boa with the push of a few buttons. The team will continue to adapt the design to meet the requirements of the client as they are determined with more extensive interviewing.

V. Fabrication/Development Process

a. Materials

The final preliminary design will be composed of many elements to ensure autonomy, non-mechanical operation, and comfort. Two Boa systems, M or H series, will be used to allow the client to autonomously operate the device. Adding the Boa system to the device allows the client to secure the restraints on the standing wheelchair independently. Both of the Boa systems will cost under $30. To ensure non-mechanical operation, meaning that the device can be operated via a bluetooth connection with the client's standing wheelchair, a Nucleo microcontroller and a bluetooth chip will be utilized. The Nucleo microcontroller is chosen due to its longevity and the ability to easily implement code. The bluetooth chip will serve as the connection between the device and the user’s wheelchair. These two devices will cost under $30 combined. The calf region of a tall pneumatic walking boot will be used to guarantee comfort for the leg restraint which will cost around $120 for both legs’ boots. The chest restraint will use nylon webbing as well as additional padding where necessary which will cost under $15 depending on how much padding was required.

b. Methods

To be completed later in the semester.

c. Final Prototype

To be completed later in the semester.

d. Testing

To be completed later in the semester.

VI. Results

To be completed later in the semester.

VII. Discussion

a. Sources of Error

To be completed later in the semester.

VIII. Conclusions

a. Overview

Spinal muscular atrophy is a neuromuscular condition that hinders voluntary muscle movement. This semester the team was tasked with helping the client, Keith, independently achieve the sitting to standing motion. Movement is beneficial for muscle strength, bone health, flexibility, posture, and a wide range of other bodily functions. The first design the team brainstormed was a stand alone device called the inversion table. However, it lacked autonomy so the focus shifted to developing a device that could be built off the client's existing standing wheelchair. The team specifically focused on altering the chest and leg constraints on the client's standing wheelchair. The three proposed designs were based on a Boa system, roller coaster harness, and pressure cuff. The boa system was determined to be the most promising for both the chest and leg constraints due to its highest rank in safety, ease of implementation, and cost. However, the system ranked high across all categories. There have since been numerous limitations, like the mobility of the client and the mounting locations available on the wheelchair, that will require the team to pivot and integrate multiple systems. The system will have to be automatic, and further discussion of the improvements can be found in the future work section.

b. Future Work

The team finally had the ability to meet with their client, in person, days before the preliminary presentation. With this new information on the specifics of the wheelchair as well as the client's abilities and limitations, the team has many ideas and objectives they would like to reach in the future. The first objective is to update design ideas to incorporate the new client requirements and come up with a way to integrate the design idea to the client's standing wheelchair. This new design idea includes automating every aspect of the design, as the client has limited arm strength and mobility. These changes may possibly force the team to look into pursuing a design different from the preliminary final design. The team would also like to integrate multiple system ideas into one design. One example of this would be the linked, synchronous restraint system of the roller coaster design. Connecting the upper chest restraints to the lower leg restraints creates a more simple system for the client. Finally, the client's wheelchair is bluetooth capable. Since the objective of the team is to create an autonomous design, the team would look into making the design bluetooth compatible to give the client or user the ability to use the joystick of the wheelchair to control the system.

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Appendix

A: Product Design Specifications

Product Design Specifications

X-Chair: Autonomous Wheelchair Restraint Adaptations
Updated: October 6th, 2020

Team Members:
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Marissa Harkness - BSAC
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Function:

Moving the body has so many benefits for the brain, muscles, bones, joints, intestines, heart, lungs and many other organs. Movement is also beneficial for a number of bodily functions such as blood flow, digestion, muscle strength, bone health, and many more. Many wheelchair users are currently unable to take advantage of these benefits due to movement challenges they experience, especially those suffering from neuromuscular conditions or spinal injuries. Neuromuscular conditions inhibit the straightening of joints, limiting the overall mobility of the patient and forcing them to stay seated in one position for the duration of the day. The cost of hiring a CNA or licenced physical therapist is quite expensive and usually is not covered by health insurance for those affected by a permanent disability. The goal of this project is to develop a device that enables wheelchair users to move in various positions, allowing them to strengthen muscles, aid in bodily functions, and help reduce their current movement limitations.

Client requirements:
- Wheelchair restraint adaptations must allow autonomous use
- Must be able to secure user while at maximum standing position
- Cannot impede entry to wheelchair via ceiling lift
- Motorized to allow straightforward implementation

Design requirements:

1. Physical and Operational Characteristics

A. *Performance requirements:* The device will be used by one individual on a daily basis, multiple times a day. The device must be in its active position during the duration of operation, for up to 8 hours at a time. The device's movement will be at the beginning and end of use and must hold in the restrained position during use and in the relaxed position when not in use. The device will need to prevent the user from being ejected out of the wheelchair when enduring non-flat surfaces, too fast of acceleration, and abrupt stops.

B. *Safety:* When designing the device, the mechanical and electrical hazards that could arise must be considered. The electrical components must not shock the user, and the device must have a manual override to prevent the user from being stuck in the chair. The mechanical restraints cannot injure the user while entering their position, and the leg restraints cannot apply an excessive force on the user while in the standing position.

C. *Accuracy and Reliability:* The chest restraint must enter its designated position within +/- 25mm during 99% of the total number of uses. The leg restraint must enter its designated position within +/- 10mm during 99% of the total number of uses.

D. *Life in Service:* This device must function for a minimum of 3-5 years with potential daily use from the end user. Each use of the device is one cycle and may have multiple cycles per day. The average lifespan of a DC brushless motor is approximately 2-4 years, or around 20,000 hours of operation [1]. The expected lifespan of a Nucleo microcontroller is 10 years in service. [2]

E. *Shelf Life:* The device must be stored in a dry environment to mitigate damage of the electrical components. Under ideal storage and usage conditions the motor should operate for a projected 3-5 years. The device microcontroller will last a projected 10 years under proper storage conditions.

F. *Operating Environment:* The device may be used in a variety of temperatures ranging from -48 °C to 46 °C[3]. The device will also encounter varying humidities ranging from 30% to 83.8% [4][5] Various weather including, but not limited to rain, lightning, snow, hail. The device may come in contact with dirt, dust, or mud during use.

G. *Ergonomics:* The device must not impede the operation of the wheelchair by the user. Additionally, the device must not leave painful or irritating marks or scratches on the subject. Therefore, no sharp edges or points may be present in the device. The restraints must provide a comfortable and secure hold on the user during operation.

H. *Size:* The device must not exceed a width of 91.5cm and a height of 203cm during usage to allow movement through a standard door frame. The leg restraints must have an opening space of at least 30cm of length and 12.5cm in width to allow the users feet to enter unimpeded.

I. *Weight:* The chest restraint and motor must not exceed a combined weight of 22.5kg to ensure the wheelchair will not tip over while the restraint is at rest. The leg restraint must not weigh more than 9.0kg to ensure the restraint can be removed if necessary and does not weigh excessively.

J. *Materials:* The device will be fabricated using aluminum or stainless steel due to the materials' properties and corrosion resistance. DC brushless motors will be used for powered components due to their longevity and performance. The Nucleo microcontroller will be used due to the longevity and simplicity of code implementation.

K. *Aesthetics, Appearance, and Finish:* The device's appearance must not stand out from the wheelchair it is attached to in order to be indistinguishable from the wheelchair. The device must be a neutral color and must not protrude excessively past the existing bounds of the wheelchair. The device's finish must be minimal to reduce attention drawn to the device.

2. Production Characteristics

A. *Quantity:* One device should be constructed for testing and usage purposes for the client.

B. *Target Product Cost:* The device should cost under the $2000 specified budget.

3. Miscellaneous

A. *Standards and Specifications:* Currently, there are no specific OSHA standards for a device similar to this. There are standards for safe patient handling and transferring that should be enforced when the client is moving from his chair to the device [6]. These standards also include solutions to maintain a safe environment for a patient. The FDA regulates medical devices that individuals use in their homes. This device would fall under the FDA's definition of a medical device, which states a medical device is "an instrument, apparatus, implement, machine ... or accessory which is … intended to affect the structure or any function of the body of man or other animals" [7]

B. *Customer:* The customer wishes to have a product that can increase his movement and blood flow. He wishes to autonomously operate his standing wheelchair to achieve an upright standing position. He does not like the feeling of being in the same position seated for a majority of the day, and hopes the design reduces that problem. The device must effectively operate over an extended period of time

C. *Patient-related concerns:* The client and potential future users will need to be able to access the device using a ceiling lift or hoyer lift.

D. *Competition:* There are currently no devices on the market that fulfill the client's needs to autonomously implement the standing wheelchair restraints.

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