Assistive Device for Wheelchair Users to Pull Pants all the Way Up

Final Report

BME 300/200

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Abstract

Individuals in wheelchairs overcome the challenge of putting on pants every day. Current products to assist the user require upper body strength, which individuals with various forms of Muscular Dystrophy (MD) lack. The client of this project, Dan Dorszynski, has Becker MD. The biggest hurdle to overcome when pulling up one's pants while in a wheelchair is separating one's bottom from the surface of the chair. The Lean and Lift design will assist in supporting the user's body weight and allow them to be removed from the chair, while their pants are pulled up via the push of a button. The design will include a height-adjustable steel frame with a cushion attached for comfort, that will be oriented in front of the wheelchair for the user to lean on. The user's pants will be clipped to a set of remote controlled (RC) winches which will pull the pants up with a user's push of a button. The desired outcome of this Lean and Lift design is to reduce the amount of time it takes the client to pull up his pants from over 7 minutes down to 3-4 minutes and minimize his discomfort, strain, and fatigue while doing so.

Table of Contents

I. Introduction

A. Impact and Motivation

The World Health Organization reports that 1% of the world's population or just over 65 million people require the use of a wheelchair [1]. Almost every single person has to put pants on daily, and when leg mobility is limited, this simple task can become a daunting challenge for wheelchair users. The task can be even more difficult when arm strength is also limited. People with muscular dystrophy, including Becker MD or Duchenne MD have a recessive disorder that leads to progressive muscular degeneration and proximal muscle weakness [2]. This muscle weakness often begins in the lower extremities, then progresses to the arms and throughout the rest of the body, which makes pulling up pants even more challenging.

The difficulty of pulling up pants can be solved by The Lean and Lift device. The Lean and Lift device is necessary because it helps people with limited strength and who are incapable of putting on their pants by themselves gain independence that they otherwise would not have. Putting on pants is a part of everyone's daily routine and when it can not be completed or is incredibly difficult to complete, it can disrupt one's ability to start their day. With the Lean and Lift device, users will be able to start the day much more efficiently and seamlessly.

The demographics of the device include any users of wheelchairs and anyone with limited arm strength who is not able to pull their pants fully up on their own. This could include anyone with Becker MD, or any other type of muscular weakness that limits one's arm and leg strength.

B. Existing Designs/Treatments

Three existing designs that currently assist with the issue of pulling pants up are the Pants Up Easy, The No Limbits Adaptive Men's Wheelchair Pants, and the Wings Pants Dressing Aid.

First is The Pants Up Easy [3]. This is a large metal frame device that can roll behind the user and lock into place. The device features padded armrests that allow the user to place their armpits over the pads and lift themselves so they can slide their pants fully over their bottom. This device requires sufficient arm and upper body strength to operate. This method is effective at fully removing the bottom from the wheelchair so the pants can be pulled to the waist. However, The Pants Up Easy is very expensive, with prices ranging from $1,497 to $3,597 depending on the model, and can not assist users with limited arm strength who cannot lift themselves.

Figure 1: Pants Up Easy Product

The second design is the No Limbits Adaptive Men's Wheelchair Pants [4]. This device is a pair of wheelchair pants that zip from the knee to the waist, and has snaps at the top to easily slide pants on. This device is relatively inexpensive and helps aid in the issue of getting pants to the waist. The caveats of this device are that it only solves the issue of the pants from the knee and doesn't help the user get their bottom off the chair. The design also requires the user to replace their current wardrobe, which is not desirable or cost effective for the user.

Figure 2: No Limbits Adaptive Men's Wheelchair Pants Product

The third design is the Wings Pants Dressing Aid [5]. This device contains two wing-like appendages which can extend and hold open a pair of pants. It allows the user to slide their feet up and while pulling up on a handle from a seated position so the pants can slide over the legs. This design also would not work for the client since the main issue is getting the pants up past his bottom. While these designs are very innovative, they are not ideal for the client based on cost, physical limitations, and personal opinions.

Figure 3: Wings Pants Dressing Aid Product

C. Problem Statement

Individuals with Becker MD, a disease that results in progressive muscular degeneration, often face physical limitations that can pose challenges in performing everyday tasks, including the simple task of pulling up pants. Current solutions are not only cost-prohibitive but also demand a level of upper-body strength that many affected individuals may not possess. This project aims to develop a prototype solution that will enable individuals with limited arm strength to autonomously pull up their pants.

II. Background

A. Physiology and Biology

Becker MD is an X-linked disorder due to a mutation in the dystrophin gene, and results in progressive muscle degeneration and proximal muscle weakness. The defective gene is located on the Xp21.2 chromosome, and it almost exclusively affects males [6]. Patients without a clear X-linked pattern of inheritance may have defects in other genes, affecting the dystrophin-associated glycoproteins. Becker MD affects people of all ages, mainly ranging from 5-60 years old [2]. The relatively rare disease occurs in about 3 to 6 out of every 100,000 births [7]. Becker MD is similar to Duchenne MD, which is more severe, has an earlier onset, and usually a lower dystrophin concentration in patients. However, Becker MD patients typically see progression of the disease at a much slower rate and Becker MD is less common [8].

In Becker MD, weakening of the lower body, including the legs and pelvis area, slowly worsens, causing difficulty walking. By age 25 to 30, the person is typically unable to walk. Weakness in the arms, neck, and other areas can be affected, however, not as severe as in the lower body [2]. This causes frequent falls, difficulty moving, and loss of muscle mass, leading many to require use of a wheelchair, while others may only need to use walking aids, such as canes or braces.

There is no known cure for Becker MD. However, there are many new drugs currently undergoing clinical testing that show significant promise in treating the disease [9]. The current goal of treatment is to control symptoms to maximize the person's quality of life. Some providers prescribe steroids to help keep a patient walking for as long as possible. Chances of survival are most often shortened if there are heart and breathing problems, and in some circumstances, death occurs due to dilated cardiomyopathy [2].

B. Design Specifications

The main goal of this project is to create a functional product that assists in the process of pulling the client's pants up while in a wheelchair, specifically from the knees and above. The device should minimize the time taken to pull pants up from seven minutes down to around three minutes and support the weight and height of a 220-230 lbs, 6 ft 2 in tall male. The device is intended for use in the home, mainly in the bedroom, and should be made out of materials compatible with an indoor environment (20-25 ℃ and humidity of 40-60% [2]). The device must be usable for five years, without the risk of failure. Any component that the client needs to lift to operate the device needs to be under 8.4 lbs to accommodate the client's limited arm strength. The product cannot exceed the size of the wheelchair by more than 1 ft around the wheelchair, which means it can't be larger than 4 ft tall, 6 ft wide, and 5 ft long. The device will be a Class I medical device according to the FDA [10] and should be within a budget of $300. A full and detailed analysis of the design specifications is laid out in the Product Design Specifications (see Appendix A).

Figure 4: Client, Dan Dorszynski, in an electric wheelchair

C. Client Information

Mr. Dan Dorszynski grew up in Wisconsin and studied both civil and environmental engineering at Stanford University. Mr. Dorszynski has Becker MD and uses an electric wheelchair to get around. The action of putting on pants is difficult for him, especially getting the pants past his thighs and over his bottom and hips, as he remains in a seated position while doing so. His current technique is to keep leaning and pulling, which takes him over seven minutes to do. He is looking for a way to reduce the time and effort required to pull up his pants.

III. Preliminary Designs

A. Lean & Lift

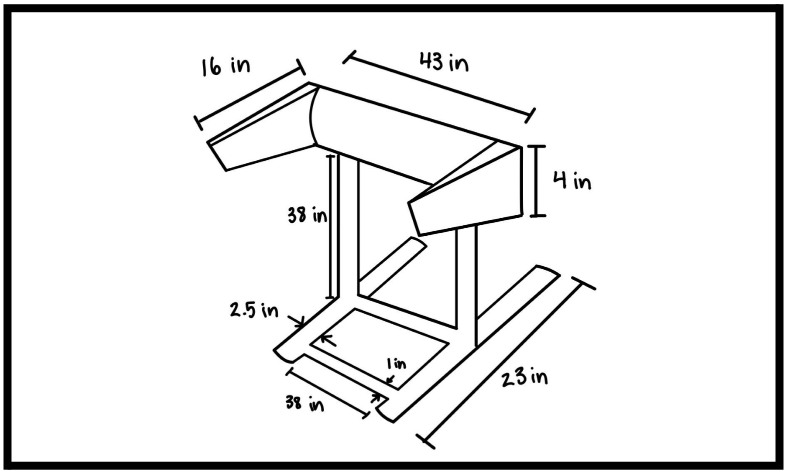


Figure 5: Lean and Lift Design Diagram

The Lean and Lift design incorporates an aluminum frame with a cylindrical cushion on the top. The design would be used so that the user can get into a leaning position with his bottom off of the wheelchair. The wheelchair would roll over the bar on the bottom that is parallel to the top cushion to act as a counterweight. In the leaned-over position, the user would be able to eliminate the need to lean back and forth to pull up his pants while sitting down. There would also be handles on the top cushion for the user to grab onto for increased stability while using the device.

B. Snap/Zip Pants

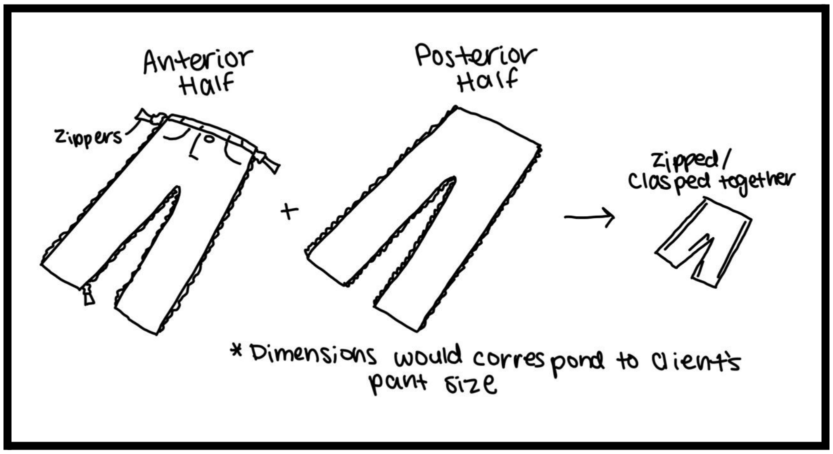


Figure 6: Snap/Zip Pants Design Diagram

The Snap/Zip pants design would involve two halves of a pair of pants that could be fastened together to fully put on a pair of pants in the sitting position. The pants would be divided into two halves, one being the front and one being the back of the pants. The edges of these halves would have either clasps or zippers to connect the two halves of the pants, creating one pair of pants. To put on the pants, the user would place the bottom half on their wheelchair before sitting down, sit down on top of the bottom half, and then place the top half of the pants on top of their legs. From there, the user would either zip the zippers or snap the clasps that would run along the edges of each half, assembling one pair of pants.

C. Suspenders

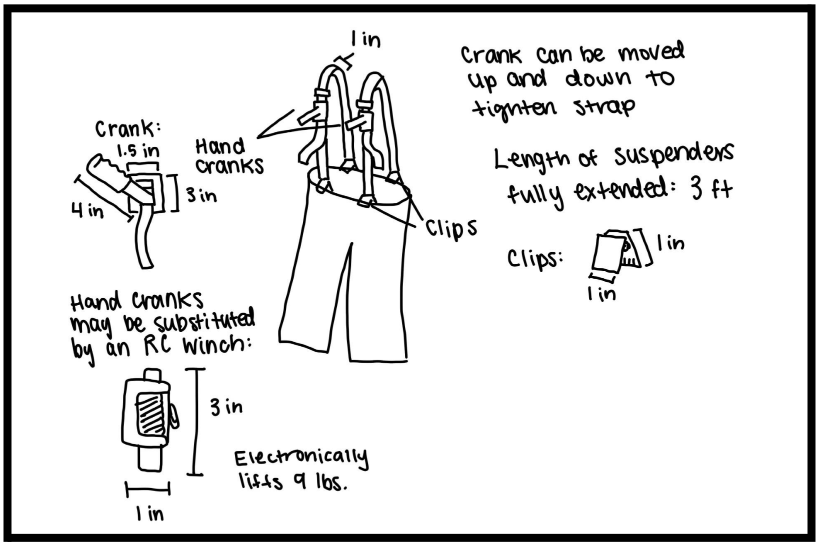


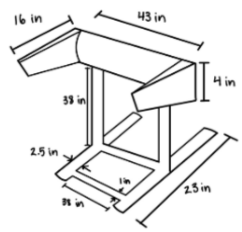
Figure 7: Suspender Design Diagram

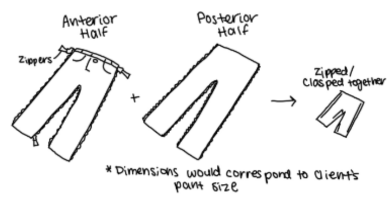
The Suspender design would allow the user to pull up their pants by integrating a cranking mechanism, similar to the crank used to tighten a backpack. The design would use a pair of suspenders with clips that would attach to the front and back sides of the pants. The user would use a hand crack that is on the suspenders to tighten the pants once they are above the knees. The hand crank could be substituted with an RC winch, which is a small, remote-controlled, mechanical device that pulls in or lets out a cable.

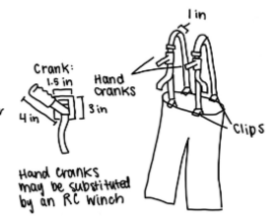
IV. Preliminary Design Evaluation

A. Design Matrix

Table 1: Preliminary Design Matrix







			Design 1: Lean and Lift		Design 2: Snap/Zip Pants		Design 3: Suspenders	
Rank	Criteria	Weighted Score	Score (out of 10)	Weighted Score	Score (out of 10)	Weighted Score	Score (out of 10)	Weighted Score
1	Effectiveness	25	9	22.5	6	15	7	17.5
2	Ease of use	25	8	20	4	10	6	15
3	Ease of fabrication	20	7	14	6	12	8	16
4	Comfort	15	10	15	9	13.5	6	9
5	Price	10	5	5	10	10	10	10
6	Safety	5	9	4.5	10	5	9	4.5
	Sum	**100**	**Sum**	**81**	**Sum**	**65.5**	**Sum**	**72**

Once the product design specifications were fully developed, the necessary design criteria were created to evaluate the effectiveness of the proposed designs. The designs were evaluated using the following criteria: Effectiveness, Ease of Use, Ease of Fabrication, Comfort, Price, and Safety.

Effectiveness:

The ability to effectively pull up the client's pants is one of the most vital requirements of the device, so it is weighted the highest (25/100). Effectiveness describes how well the device improves the ability of the client to put on his pants relative to his current method. The efficiency and amount of time required to put on the pants are the two main factors in the effectiveness category. The device should allow the client to pull his pants fully over his bottom in less time and with less strain than current methods. The Lean and Lift design scored highest (9/10) because it would solve the most significant problem for the client, lifting his bottom off of the wheelchair seat. However, it may be difficult for the client to pull his pants up once he is leaned over, due to limited arm mobility. The Suspenders design scored second highest (7/10) because the potential for an electric crank (RC winch) could make the design hands free, but this device would be hard to use since the client's bottom will still be in the chair. The Snap/Zip pants scored the lowest (6/10) because the bottom half of the pants would need to be aligned perfectly each time the client wants to put on the pants, which is not ideal. Also, when the client sits on the bottom half of pants, the bottom half could become bunched up or move so that the client couldn't zip/snap the bottom half to the top half of the pants.

Ease of Use:

Ease of use is defined as the amount of effort required to use the device and pull up pants. Ease of use is also weighted highest (25/100) because a major requirement for the final design is that it makes it easier for the client to pull up pants. The Lean and Lift scored the highest (8/10) because the client does not have to transition out of his wheelchair, he will only need to lean forward using the controls already built into his wheelchair. The Suspenders scored the second highest (6/10) since the device is easy to use, but it may be difficult for the client to attach his suspenders to his pants properly and would put a weight on the users shoulders from the suspenders. The suspenders could require more force than the client can easily offer, making it difficult and inconvenient to use. The Snap/Zip Pants design scored lowest (4/10) for this criterion because the client's lack of arm strength and hand dexterity would make it very difficult to align zippers or snap many snaps.

Ease of Fabrication:

Ease of fabrication considers how difficult the device will be to fabricate considering the materials required, time limitations, and effort to complete. Ease of fabrication is weighted relatively high (20/100) because the design must be feasible to fabricate within one semester. The Suspenders design scored the highest (8/10) because the design would only require a pair of suspenders and a crank, which would be relatively simple to source and combine. The Lean and Lift design scored second highest (7/10) because this design would require the frame to be welded together, which is a lengthy and difficult method of fabrication. There are some options for purchasing prefabricated parts for modification, but this would require the most mechanical knowledge and safety testing. The Snap/Zip Pants design scored the lowest (6/10) because it would be difficult to modify all of the client's existing pants and source a tailor or learn to sew.

Comfort:

The comfort of the design is defined as the comfort of the client while using the device. Since the device will be used daily, it is important for the device to be comfortable to use and should not put the client in any uncomfortable positions for a prolonged time. Based on client feedback, comfort is weighted lower than other factors, (15/100) since a more efficient device is preferred even if comfort is slightly sacrificed. The Lean and Lift design scored highest (10/10) because the cushion material on top would not cause any irritation on the client's abdomen, yet firm enough to keep the client in place and can be operated within the client's wheelchair. The Snap/Zip Pants design scored closely behind (9/10) as the pants worn by the client would be similar to regular pants, but the zippers or snaps could potentially cause slight irritation to the skin. The Suspender design scored lowest (6/10) because the suspenders could irritate the client when rubbing against the shoulders and front/back sides of his body, and cranking of the suspenders could cause discomfort and muscle fatigue.

Price:

Price is defined as the total cost to produce the device. Price is weighted less than the other categories (10/100) due to the flexible budget of the project. The initial budget allotment will be increased if a more ambitious design is selected that can improve the dressing experience significantly for the client. The Snap/Zip pants scored highest (10/10) because the materials would mainly be the fabric for the pants and zippers and sewing materials which would be well within the budget of the project. The Suspender design scored equally high (10/10) because the materials would be fabric and hand cranks, which are well within the budget of the project. The Lean and Lift scored lowest (5/10) because the device would require the most amount of materials compared to the other two designs, including more expensive materials such as the metal and padding.

Safety:

Safety is weighted the lowest (5/100) because it is the lowest consideration for the designs based on client feedback. The device must be used while the client is in a wheelchair and the act of pulling up pants is a low-risk activity. The Snap/Zip Pants scored highest (10/10) for safety because this product allows the client to stay seated the whole time and snaps/zippers pose no risk to the client's safety. The Lean and Lift scored closely behind (9/10) because it allows the client to keep his feet on the ground and only lean his body forward, but the design could possibly tip if it is not built correctly. Potentially adding a counterweight would reduce the risk of tipping, making the design safer. The Suspenders scored equally (9/10) because the crank feature of the design could pinch fingers, but it doesn't pose a significant safety threat.

B. <u>Proposed Final Design</u>

Based on the criteria above, the Lean and Lift design scored the highest. After reviewing the designs from the design matrix with the client, it was decided to combine the Lean and Lift with the second-highest-scoring Suspenders design. This combines the best aspects of both designs. The main issue with the Suspender design was that it did not elevate the client's bottom off of his wheelchair seat. Combining it with the Lean and Lift design eliminates this problem and brings in the Lean and Lift's superior aspects of effectiveness, ease of use, and comfort. The Suspenders were deemed to be the easiest to fabricate and the best price, so this design should not significantly increase the burden of fabricating the final design.

After further research of materials and testing of preliminary prototype designs, the proposed final design changed to become the same Lean and Lift frame constructed from a standing desk frame with a cushion and floor support beam. The winches are attached to bars protruding from the frame instead of a suspender design, to allow for more optimal placement of the winches and increase comfort for the client. The winches can clip onto the waist of the client's pants with its cords fully extended. The client will then be able to push a button to retrieve the winch cords and pull his pants up vertically as he leans on the Lean and Lift Device.

V. Fabrication/Development Process

A. Materials

For the Lean and Lift device, an adjustable steel alloy standing desk frame was purchased for modification, to eliminate all welding due to a lack of experience and feasibility of completing a functional prototype in one semester. High-density polyurethane foam cushion, similar to that of a doctor's exam table, will be attached to the top bar that the user leans over for comfort. For attachment of the foam to the steel alloy, a polyurethane-based adhesive will be used. Another steel bar will also be added to the bottom of the standing desk frame so that the client's wheelchair could roll over to act as a counterweight. The winch component will include an RC winch that will allow the user to electronically pull up his pants. The RC winch requires an RC transmitter and receiver, batteries, and an electronic speed controller (ESC). Steel bars will be attached to the top of the standing desk frame, extending out towards the center of the frame, and the RC winches can be attached at the end of these steel bars. This will allow for the RC winches to pull directly upward. Refer to Appendix B for details of the materials purchased to fabricate the device.

B. Methods

The standing desk frame was assembled according to the manufacturer's instructions, then a steel bar is screwed to the bottom of the frame between anti-slip feet and legs of the frame. The steel bar is cut to the width of the frame and holes are drilled to match the distance between the two holes in the standing desk frame that attach the anti-slip feet to the legs. Next, the cushion is attached to the frame after using a file to roughen the steel bar (shown in Figure 8) by gluing it with the polyurethane adhesive and securing it with zip ties. Finally, the foam is covered with fabric (shown in Figure 9) to make the design more visually pleasing.

To attach the RC winches, steel bars must be attached to the protruding beams of the standing desk frame (shown in Figure 10). The RC winches must face inward so that the cords will pull straight up from where they are attached to the pants. The steel bars are cut so that the distance between the client and the attached bar is 1.5-2 in. Holes are drilled into the steel bars so they can be easily attached to the standing desk frame. The winches will be attached to the free ends of the steel bars with a polyurethane adhesive. Refer to Appendix C for a detailed fabrication protocol.

Figure 8: Standing Desk with Steel Bar Attached to Bottom

Figure 9: Standing Desk Frame with Foam Cushion Attached

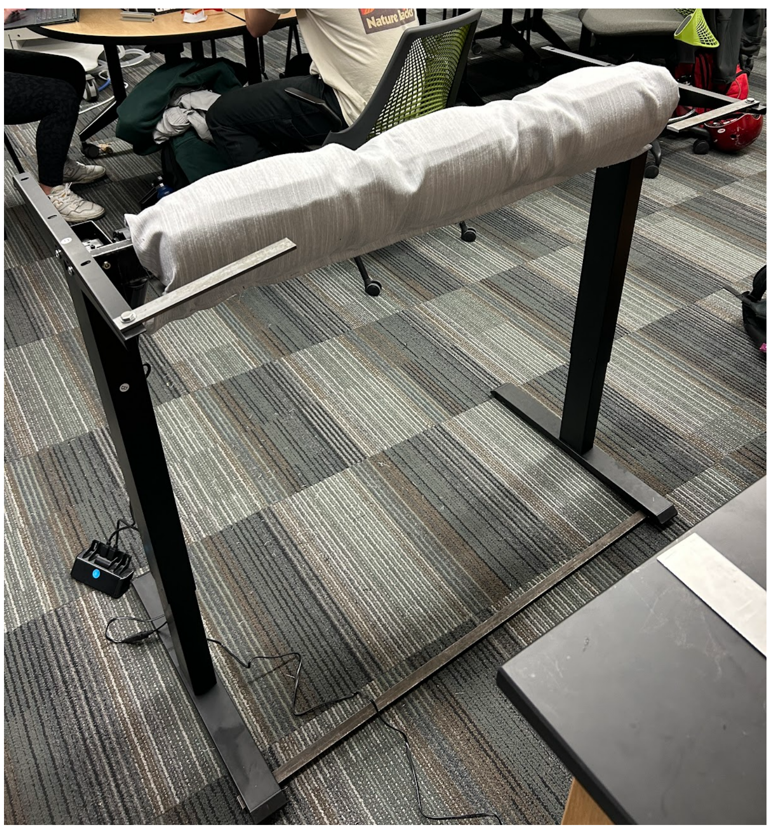


Figure 10: Standing Desk Frame with Winch Bars Attached

C. <u>Final Prototype</u>

The final prototype (shown in Figure 11) consists of a steel alloy metal frame with attached high-density polyurethane cushions covered with fabric along the main crossbar of the frame for the client to lean on. A steel bar is attached to the bottom of the frame for the front two wheels of the client's 350 lb wheelchair to roll on top of to act as a counterweight to prevent tipping and ensure that the device is stable.

To pull up the client's pants, two winches are each attached to the end of an 8 in steel bar that is attached to the protruding beams of the main metal frame (shown in Figure 12). The winches are facing inwards and the steel bars are perpendicular to the protruding beams. The client will be able to attach the clips to the sides of his pants at his knees and get into a forward leaning position using his electric wheelchair. Once leaning against the padded surface, the client will use the RC winch remotes to electronically pull his pants up to his waistline.

Figure 11: Front Facing View of Final Prototype

Figure 12: Top View of Final Prototype

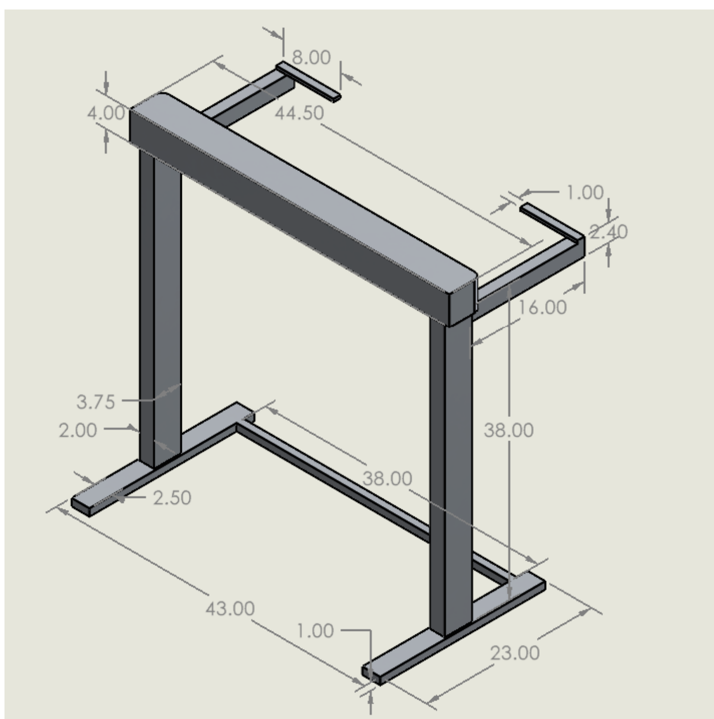


Figure 13: SolidWorks Model of Final Prototype with Dimensions in Inches

VI. Testing

A. Client Strength Testing:

The client will lift varying amounts of weight from a seated position with one arm. If the client was able to pull the weight completely off of the ground, it will be marked as a success - if the client is incapable of lifting the weight off of the ground, it will be considered a failure [see Appendix D for testing protocols]. This strength testing is important because it gives a baseline evaluation of how much weight the client can pull. This will inform how to design the leaning device so the client will never need to pull more weight than they are able to.

B. RC Winch Path Testing:

The RC winch path testing will reveal the most effective angle that the RC winches can pull up the pants. The RC winches will be placed at decreasing lengths away from a pair of shorts. The time it takes for the shorts to be pulled up from floor height to the position of the winches will be measured and the velocity will be calculated. This RC winch path testing is important to the design since it assists in optimizing the speed at which the user can pull up their pants.

C. RC Winch Strength Testing:

The RC winch strength testing will evaluate the maximum weight the RC winches can pull up at the angle chosen from the RC winch path testing. The average weight of an individual's pants is 0.75 lbs [11]. Various weights will be attached to the RC winches ranging from 1.0-2.5 lbs and record if the RC winches pass or fail under that weight.

D. Frame Strength Testing:

The frame strength testing will evaluate if the frame can withstand the weight and counterweight of the user and wheelchair without deformation. Varying weights will be placed on the top of the frame to simulate the user's weight and a 350 lbs weight will be placed on the bottom bar to simulate the weight of the wheelchair. The testing will quantify as a pass so long as no visible deformation is observed and the device does not topple.

E. Solidworks Stress and Displacement Testing:

The Solidworks stress and displacement testing will evaluate the factor of safety of the frame, which demonstrates how much stronger the frame is than what it will need to be for its purpose, the displacement of the frame, and the yield stress due to the forces acting on the frame. The two forces acting on the frame are the 2 lbs vertical force downward, simulating the tension of the cable from the RC winch, and a 230 lbs force acting at a 45° angle, simulating the user's weight leaning on the frame. The frame is fixed to the ground in the simulation. A steel alloy material is added to the frame that is linear elastic isotropic with a yield strength of 89,984.6 lbs/in^2 and tensile strength of 104,982.1 lbs/in^2.

VII. Results

Client Strength Testing

Table 2: Results from the client strength testing

Trial	Weight (lbs)	Outcome
1	2.8 lbs	Pass
2	5 lbs	Pass
3	8.4 lbs	Pass
4	12.8 lbs	Fail

As mentioned in the testing protocol [Appendix D], lift attempts where the weight was fully off the ground were marked as a pass, and attempts where the client was unable to lift if fully off of the ground were marked as a fail.

The results above show that the client is capable of lifting at least 8.4 lbs from a seated position with 1 arm; however he is not able to lift weights exceeding 12.8 lbs.

RC Winch Angle

Table 3: RC Winch Angle vs. Speed

Trial	**Angle (degrees)**	**Speed (in/second)**
1	27.98° (8.5 in away)	19.220
2	23.63° (7 in away)	14.001
3	18.97° (5.5 in away)	9.912
4	10.62° (3 in away)	7.861
5	6.24° (1.75 in away)	5.666

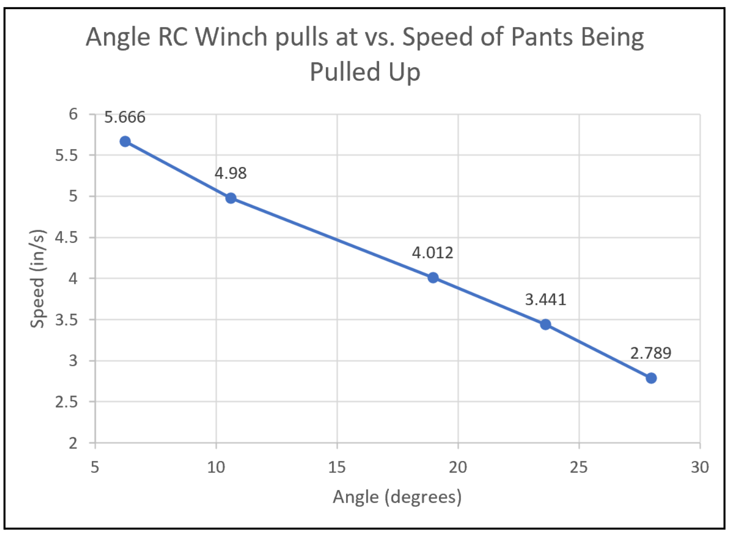


Figure 14: Angle of RC Winch vs. Speed Graph

The angle is the angle that the cables of RC winch make with the ground relative to the vertical while clipped to the pants. The more vertical the vector of the path, the smaller the angle is and the closer the winches are positioned to the client.

As seen in the graph above, the RC winches pull the pants up the quickest at positions closer to the user.

RC Winch Strength

Table 4: RC Winch Maximum Weight

Trial	**Weight (lbs)**	**Outcome**
1	1.0 lb	Pass
2	1.5 lbs	Pass
3	2.0 lbs	Pass
4	2.5 lbs	Pass

The RC winch testing results above demonstrates that the RC winch is capable of pulling up 2.5 lbs individually, which exceeds the weight of an average pair of pants twofold [11].

Frame Strength

Table 5 : Frame Strength

Trial	**Weight (lbs)**	**Outcome**
1	220 lbs	Pass
2	230 lbs	Pass
3	240 lbs	Pass

The testing above was conducted with the 350 lbs acting as a counterweight on the below crossbar to observe if the device will topple as well. Each trial was considered a pass if no visible deformation was observed after 4 minutes of the trial weights were applied to the padded crossbar.

Solidworks Stress and Displacement Testing

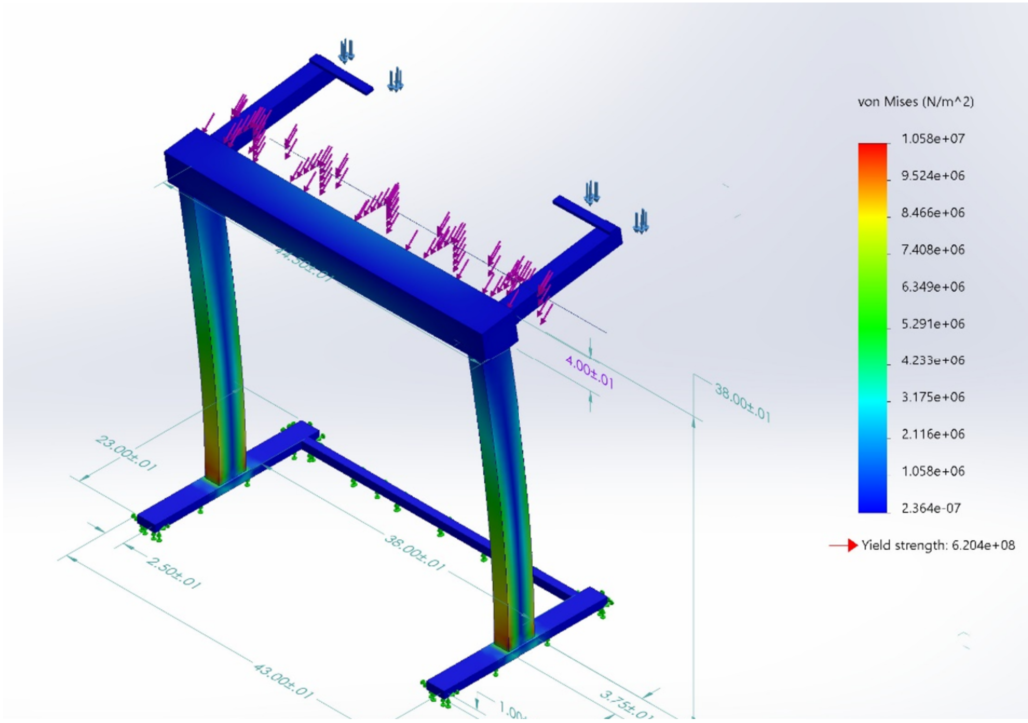


Figure 15: Solidworks von Mises Stress of Lean and Lift Device

Figure 14 shows the results of the stress testing from Solidworks. The yield strength of the model is 6.204e+8, which is the amount of stress that the frame can handle before it undergoes a permanent change in shape. A red color indicates a high stress in the model and a blue color indicates low stress. The maximum observed stress was 1,534.5 lbs/in^2, which is over 50 times less than the yield strength of steel.

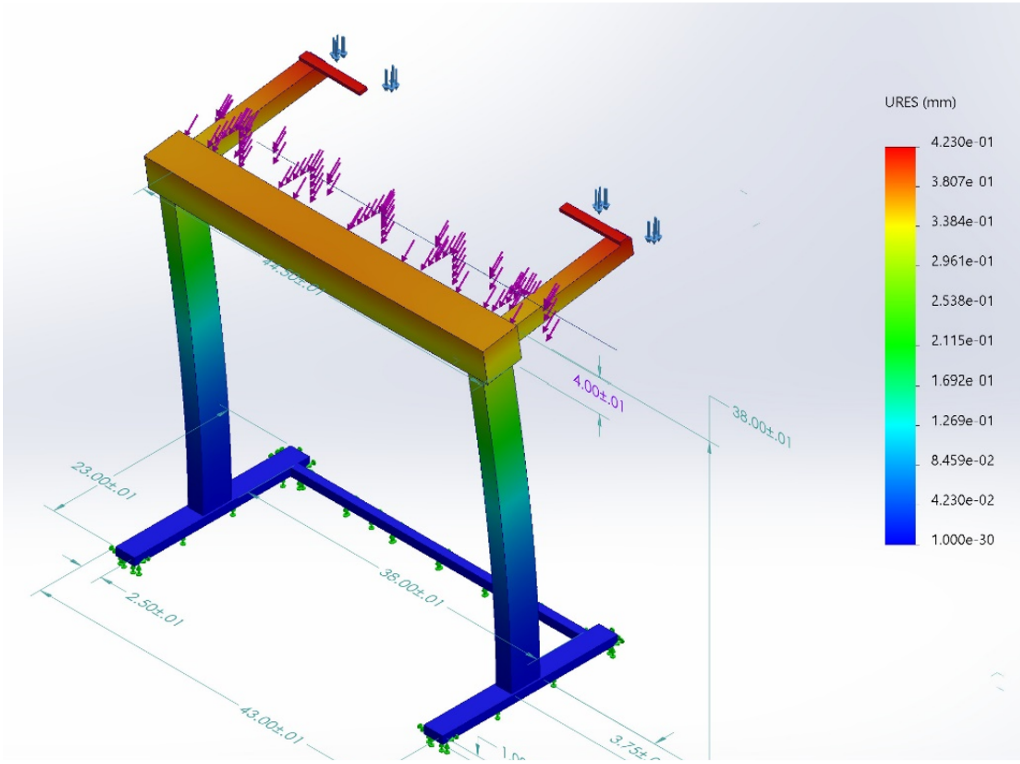


Figure 16: Solidworks Displacement of Lean and Lift Device

The displacement results of the lean and lift device are shown in Figure 15. Displacement refers to the change in position of the model under the given loads. The red tones indicate a higher displacement of the model and the blue tones indicate a lower displacement. The maximum displacement is observed on the bars facing inward where the winches are attached to the device. The highest displacement value is 0.016 in.

VIII. Discussion

From the client strength testing, it was determined that the maximum vertical pulling force of the client does not exceed 8.4 lbs. This required the team to fabricate a frame that is lower than the client while he is in the wheelchair, enabling him to use the controls built into his wheelchair to get into the leaned-over position. Additionally, the height of the device is electronically adjustable, further assisting the client leaning over the device in the proper position. Since the client has limited arm strength and mobility, the addition of RC winches to electronically pull up his pants further makes the device hands free, reducing strain and fatigue for the client.

The Solidworks stress and deformation testing results were used to evaluate whether the design is capable of withstanding the weight of the client. The Solidworks testing results act as a proof of concept before the materials are purchased and the prototype itself is tested. The stress results showed that the maximum stress occurs at the base of the frame. However, this stress is much less than the yield stress of steel as mentioned in the results, proving that the device is capable of withstanding the stresses induced by the user. The deformation results also were indicative that the prototype will work. The maximum deformation was 0.016 in, and this occurred at the attachment point of the winches to the steel bars attached to the frame, the maximum deformation on the rest of the device was 0.015 in at the center of the leaning bar. These deformation values are not large enough to be observed nor relevant to the function of the device. Overall, the Solidworks testing results were conclusive that the device is capable of working in theory; however further prototype testing will need to be conducted once the product has been fabricated. In the future, a dynamic simulation of the Solidworks model would allow the team to analyze all the moving parts on the frame, including the winches pulling mechanism and the user leaning mechanism.

The frame testing and RC winch strength testing were essential in determining if the device is capable of meeting the minimum requirements of the design criteria. The frame testing evaluated whether the device is capable of withstanding the weight of the client for a prolonged period of time. The length of time that is aimed for the client to use the device is 3-4 minutes, so

4 minutes is used during the test. A maximum weight of 240 lbs applied to the top bar of the device whilst a 350 lb weight was applied to the below crossbar passed the test due to no deformation and no toppling occurring during the test. This shows that the product is capable of being used by the client to pull up his pants. The RC winch testing evaluated the amount of weight the winches are capable of pulling by themselves. This test requires that at a bare minimum the winches are capable of pulling up an average pair of pants, which weigh around 0.75 lbs. The testing results show that each winch is capable of lifting at least 2.5 lbs, which is over 3 times the weight the average pair of pants weighs, so the winches are more than strong enough to pull up any pair of pants the client has.

The final prototype testing that was conducted was the RC winch path testing. This testing was essential to evaluate the most optimal location to attach the winches to the device. The testing results concluded that the RC winches were most effective when located closest to the user. The main reason as to why the different vector paths of the winches had varying speeds in pulling up the pants was due to the negative work induced on eachother. The further the winches were from the client, the more the winches pulled apart instead of up.

Since the product is for the client, continuous work with Dan Dorszynski will be conducted to ensure the success of the prototype. To eliminate bias and error in testing, all final physical tests will be conducted with the client using the device to maximize satisfaction. Discomfort, dislikes, and suggestions will be noted and the feedback will be implemented to the best of the team's ability, however the client sustained an injury and is unable to conduct testing himself at this time.

IX. Conclusions

Everyone deserves to have their own autonomy and the tools they need to be independent. Dan Dorsynski, the client and a man with Becker MD, has physical limitations that prevent him from being able to pull his pants up all the way. By creating a device that would aid in the process of the client getting dressed in the morning, his life can be made easier by saving him time and effort, while getting ready independently.

The design used to aid Dan's dressing process is a steel frame-supported cushion that he can lean on, in addition to a lifting winch component that would clip onto his pants and electronically pull his pants up. Once clipping the winch clips onto his pants waist, Dan will be able to push a button to retrieve the winch cords, pulling up his pants all the way and allowing him to get dressed in a faster and easier fashion than before.

X. References

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XI. Appendix

A. Product Design Specifications

Function:

Muscular dystrophy (MD) is a genetic disease that causes progressive weakness and degeneration of skeletal muscles. A patient with Becker MD, a type of MD caused by a mutation in the dystrophin gene [10], has physical limitations that make it difficult to pull up their pants all the way when getting dressed. The pants can be pulled up to the knees easily, and then a combination of leaning and pulling, along with frequent assistance, is needed to get the pants where they need to be. The total time taken is around 7 minutes. To minimize the time taken and eliminate the stress caused on the patient to pull up the pants, a two-part assistive device can be used. The first part of the system, the Lean and Lift device, is a stand-alone device that when positioned in front of the user, will allow the user to lean over the top to raise the lower body off the wheelchair. The Lean and Lift will be able to withhold a 230-lb, 6-ft-2-in male. The second part of the system, the Suspender device, will attach to the pants when at the knees and go around the shoulders. When the user is in the leaned-over position on top of the Lean and Lift device, the user will pull a string, attached to the suspenders, that will pull the pants up until comfortable. The amount of arm strength provided by the user with MD is limited, so the entire system will not require lifting more than 8.4 lbs. The time required to operate the device should not exceed 3 minutes.

Client Requirements:

- Functional product that assists the process of pulling pants up while sitting in a wheelchair, especially from knees and above
- Support the weight and height of 220-230 pound, 6-foot-2-inch tall male
- Must be usable without fully standing up
- Materials must be durable for 5 years of daily use
- Budget must be within $300

Design Requirements:

1. **Physical and Operational Characteristics**
    a. *Performance Requirements:* The Lean and Lift device will allow the user to safely get out of a wheelchair without risk of falling or the device slipping on the

ground. The Lean and Lift device will support a 230 lb weight without tipping and not cause any discomfort to the user on the upper body. The device will pull pants from the knees to the waistline without the risk of coming unattached from the pants or sliding off the shoulders during operation. The Lean and Lift and winch system will pull the user's pants up without the need of assistance in about 3 minutes.

b. *Safety:* The device should withstand 230 pounds of force for 5 years, without the risk of failure. All mechanical parts must be without sharp edges or pinch points to prevent user injury. For possible electrical elements, the device should ensure operation on a low voltage to minimize the risk of electric shock. The device should implement fire-resistant materials in areas where the risk of sparks or high temperatures is present. The device must adhere to relevant safety standards for machinery safety and risk management in medical devices. Clear operational instructions should be given to the user to ensure safe and effective use.

c. *Accuracy and Reliability:* The device should pull up pants from the knees to fully over the client's bottom without exertion on the client or use of any assistance. The device should lift the user’s lower body off the wheelchair without the risk of falling. The device should hold up a force of 230 lbs during operation. The device should continue to pull up the client’s pants up to 10 cycles daily and function for at least 5 years without failure.

d. *Life in Service:* The device should minimize the time taken to pull pants up from 7 minutes to around 3-4 minutes. The device is to be used every time the client puts on a pair of pants (once a day). The device should have easily repairable components with the intention that the device can be used for at least 5 years by the client without modification.

e. *Shelf Life:* The device should remain fully functional for 5 years and its components can be replaced or fixed easily.

f. *Operating Environment:* The device is intended for use in the home, mainly in the bedroom or bathroom. The device should be made out of materials compatible with an indoor environment temperature (20-25 ℃) and humidity (40-60 %) [10]. The device may be free-standing, attached to the client's wheelchair, or mounted on a wall.

g. *Ergonomics:* The device will accommodate a patient with a height of 6-ft-2-in and a weight ranging from 220-230 lbs. After the device is initially set up, no component should require the user to lift more than 8.4 lbs. Large, easy-to-grab knobs and handles should be integrated into the design for easy use. The device should include a bar on the bottom of the base for the wheelchair to roll over to counteract the weight of the user on the device. The device should not cause any unnecessary strain or fatigue to the user. Electric components should be integrated into the design so the user only has to press a button to operate the device. The width and height of the device should be easily adjustable so the user can choose the dimensions best suited for them.

h. *Size:* The product cannot exceed the size of the wheelchair by more than 1 foot around the wheelchair; so no larger than 4 ft tall, 6 ft wide, and 5 ft long.

i. *Weight:* Any component of the device that the client needs to lift needs to be under 8.4 lbs to accommodate the client's limited arm strength. The total weight of the device may be up to 50 lbs because it will not be moved once initially set up with assistance.

j. *Materials:* The device base should be made of durable material with a strength equal to or greater than the total load plus the factor of safety. A foam material similar to that of an exam table at the doctor's office should be placed where the user will lean on the device for comfort. Any electric materials that will be used to pull the pants up should include controls, like a remote or button, so the user can easily operate the device.

k. *Aesthetics, Appearance, and Finish:* The color scheme of the product should prioritize clarity and visibility. High-contrast color combinations like white/black [1] should be used for controls and indicators. The device's shape should complement the user's body movements when pulling up pants and wheelchair configuration. For a handheld device, the texture should exhibit the following characteristics: soft, non-shiny, smooth, warm, and non-sticky to optimize the user's grip [2].

2. Production Characteristics

a. *Quantity:* One prototype for individual use by the client is needed.

b. *Target Product Cost:* The client desires a functional prototype within a $300 budget.

3. Miscellaneous

a. *Standards and Specifications:* The device will be a Class I medical device according to the FDA [3]. Relevant FDA regulations include:

   i. Electronic Product Radiation Regulation - 21 CFR 1000.1 [4]

   ii. Establishment Registration - 21 CFR Part 807 [5]

The device will also be required to follow Rehabilitation Engineering and Assistive Technology Society of North America (RESNA), which specifies standards for wheelchairs, wheelchair devices, and scooters [6]. Such regulations and standards include:

   i. RESNA WC-1 Wheelchairs – Volume 1: Requirements and Test Methods for Wheelchairs (including Scooters)

ii. RESNA WC-2 Wheelchairs – Volume 2: Additional Requirements for Wheelchairs (including Scooters) with Electrical Systems

b. *Customer:* The client is Mr. Dan Dorszynski. He grew up in Wisconsin and has studied both civil and environmental engineering at Stanford. Mr. Dorszynski has Becker MD and uses an electric wheelchair. The action of putting on pants is difficult, especially past the knees, as he often has to keep leaning and pulling, which takes him about seven minutes to do and a lot of effort. He typically wears athletic pants, such as golf pants that have belt loops. Mr. Dorszynski has voiced he doesn't mind if the solution is electric, manual, cloth, or any specific material/device.

c. *Competition:* There are a few similar items that aid people with pulling up their pants. One of the most popular products is one called Pants Up Easy. This device can either be attached to the wheelchair, wall, or portable. It is made up of two pads that lie above the user's shoulders so they can hoist themselves up, allowing them to pull up their pants. Pants Up Easy is very costly, ranging from $1,497 to $3,597, depending on the model [7]. Another is called the Wings-Pants Dressing Aid, which is a much cheaper option, retailing for $49.50. The product holds the pants open and is easily adjustable by opening the release and pulling outward, allowing the user to slide up the device and pants simply [8]. Both designs are efficient, but costly and require sufficient arm strength.

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B. <u>Materials and Costs</u>

Table 3: **Expense Table**

Item	Description	Manufacturer	Part Number	Date	QTY	Cost Each	Total	Link
Component 1: Lean and Lift Frame								
Polyurethane Foam Sheet	Polyurethane foam sheet for cushion portion of Lean and Lift design	GRAINGER APPROVED	5GCN1	10/25/23	3	$14.25	$42.75	https://www.grainger.com/product/GRAINGER-APPROVED-Polyurethane-Sheet-Std-5GCN1
Adjustable Electronic Desk Frame	Steel alloy Stand Up Desk Frame	Win Up Time	DDJ-SSZJ-B	10/25/23	1	$109.99	$109.99	Amazon.com: Win Up Time Standing Desk Frame Legs- Adjustable Desk Frame, Sit Stand Desk Frame, Smart Controller System for 43"-70" Desk Top, Home& Office DIY Workstation

								(Black Frame Only) : Office Products
Loctite PL Premium Construction Adhesive	Glue that will attach polyurethane foam padding to steel desk frame	Loctite	N/A	11/10/23	1	$10.98	$10.98	Loctite PL Premium Fast Grab Polyurethane Construction Adhesive, 10 fl oz, 1, Cartridge: Cyanoacrylate Adhesives: Amazon.com: Industrial & Scientific
Mild Steel Bar	Mild steel bar to be mounted on base of legs to act as safety feature	UW TEAM Lab	N/A	11/29/23	1	$27.50	$27.50	N/A
Component 2								
RC Winches	INJORA Metal Automatic Winch Wireless Remote Controller Systemription	INJORA	SCX10 90046 TRX4	10/25/23	2	$31.98	$63.96	https://www.amazon.com/INJORA-Automatic-Wireless-Remote-Controller/dp/B083NTSH1J/ref=sr_1_2?keywords=rc%2Bwinch&qid=1697397537&sr=8-2&th=1
Hold'Em 1 1/8" Polished Nickel Plated Clips	Clips that will attach to winch to clip onto clients pants to pull up	HOLD'EM	B06X95MZ9P	10/25/23	1	$5.80	$5.80	https://www.amazon.com/HoldEm-Polished-Suspender-Pacifier-Pacifier-5pc/dp/B071NDV92X/ref=sr_1_9?crid=LURUJTZV14D6&keywords=suspender%2Bclips&qid=1698275211&sprefix=suspender%2Bclips%2Caps%2C80&sr=8-9&th=1
Lithium Battery Packs (2 Pack)	URGENEX 2000mAh 7.4 Li-ion Battery	URGENEX	B0B561XZRL	11/10/23	1	$24.99	$24.99	Amazon.com: URGENEX 2000mAh 7.4 V Li-ion Battery with Deans T Plug 2S Rechargeable RC Battery Fit for WLtoys 4WD High Speed RC Cars and Most 1/10, 1/12, 1/16 Scale RC Cars Trucks with 7.4V

								Battery Charger : Toys & Games
TOTAL:								**$285.97**

C. Fabrication Protocol

Lean and Lift Standing Frame

1. Assemble standing desk according to manufacturer's instructions
2. Assembling Bottom Support Beam to Standing Desk Frame
    a. Cut thin mild steel bar to 43.5 in
    b. Drill 2 ⅝ in holes in bar, each 1.33 in from the end of the bar
    c. Unscrew anti-slip feet from the bottom of the standing desk, line up steel bar holes with holes of feet, and screw back in feet
3. Attaching Foam Cushion to Standing Desk Frame
    a. Cut 3 pieces of high density polyurethane foam to 8x12 in
    b. Use a file to remove coating of middle standing desk beam and prep surface
    c. Attach 3 foam pieces along main middle beam of standing desk frame using polyurethane based adhesive, secure with zip ties
    d. Cover with fabric and staple in place
4. Attaching Winch Bars
    a. Drill ⅜ in holes ¼ in from one end of 2 8 in steel bars

    b. Line up holes of steel bars with hole of protruding beams of standing desk and screw into place with a washer, nut and bolt- bars should be perpendicular from the beams facing inward to the center of the frame

5. Attaching Winches
    a. Apply polyurethane based adhesive to bottom side of winches
    b. Place winches onto the free ends of the steel bars that are facing inward with the clip side of the winch facing inwards toward the center of the frame
    c. Apply clamps the the winches and bars until the polyurethane adhesive dries

D. <u>Testing Protocol</u>

Client Strength Testing Protocol

1. The client will sit in his wheelchair and grab the weighted backpack with one arm
2. The client will begin with 2.8 lbs
3. If the client is able to lift the weight off of the ground it counts as a pass, if the client is unable to lift the weight it counts as a fail
4. Repeat trials 1 through 3 for increasing amounts of weight; 5 lbs, 8.4 lbs, and 12.8 lbs

RC Winch Path Testing Protocol

1. Place winches at proper position for testing position, for trial 1 it will be 8.5 inches away from the clients position.
2. Release the clips from the winches until it reaches the floor, then attach the pair of shorts.
3. Upon the start of the winches pulling the pair of shorts up, start the timer and pull the shorts up with the winches

4. Once the winches pull all the way up, stop the timer
5. Calculate the velocity in inches per second and repeat the process for each respective trial.

RC Winch Strength Testing Protocol

1. Hook the spring gauge to the RC winch attachment
2. Activate the winches and pull on the spring gauge to observe the strength of the winches
3. Record the maximum observed strength

Frame Strength Testing Protocol

1. Observe the initial height of the frame
2. Lean over the cushioned frame with the desired testing weight
3. Stay on the frame for 4 minutes
4. Record the final height of the frame