Portable Elevating and Transfer Seat for Wheelchair Users

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Abstract

Throughout the world, there is a large population of people that are physically impaired which requires the use of a wheelchair. In an effort to keep their independence and perform daily tasks, wheelchairs are used to the best of their abilities, but there are still limitations. One aspect of being in a wheelchair that patients struggle with is transferring onto higher surfaces without the help of others. There no affordable devices on the market that can attach to wheelchairs and provide vertical and lateral assistance when transferring. This team's goal was to create a device that effectively raises and laterally moves a wheelchair seat for a patient with muscular dystrophy. The final design uses a manual scissor lift, guide rails, and a comfortable cushion to meet the design specifications. A ratchet will be used to lift the manual scissors lift up and down. Once complete, the device was evaluated based on the number of cranks needed from a socket wrench to raise the seat and the forces needed to move the seat laterally. In the future, the device could be improved by doing testing with users having limited arm strength, a better locking mechanism could be found, and an automated vertical and lateral transfer could be designed.

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I. Introduction

A reported 3.6 million people in the United States over the age of 15 use a wheelchair, with that number increasing each year due to the aging baby boomer population [1]. Wheelchairs allow people with disabilities a more independent lifestyle than they may not otherwise have had. The ADA defines a person with a disability as as "a person who has a physical or mental impairment that substantially limits one or more major life activity" [2]. In 2015, 12.6% of people in the United States were reported as living with a disability [3]. This number grows with every passing year. In the same report, it was also noted that 1 in 5 of people living with a disability also live in poverty. This is due to a high unemployment rate among individuals with disabilities. Wheelchairs provide some people with the significant advantage of being able to travel, work outside the home, and perform everyday activities that they otherwise may not be able to do. While they provide the benefit of increased independence, wheelchair users are often limited when they cannot elevate themselves or need assistance to transfer into or out of their wheelchair. Because manual transfer is one of the most strenuous and pain-causing activities for people using wheelchairs [4], transfer support devices are needed to reduce actions that require the user to support their own weight while transferring. Furthermore, it has been shown that during transfer, the maximum vertical reaction forces generated through the hands increase as the height disparity between surfaces increases (with the target surface being higher) [5]. Thus, seat elevation can help to reduce the risk of injury, pain, and discomfort caused by these types of higher-elevation transfers.

There are existing wheelchairs on the market that provide seat elevation as a built-in feature, however there are many disadvantages to existing products. An example of this is the MobiLife PMV X22 power wheelchair, which can raise the seat up to 56 cm without putting strain on the user [6]. The downside of this device and similar wheelchairs is that not all people qualify to receive insurance coverage for the elevation and other customizable features [7]. Additionally, users may still have trouble moving laterally to manually transfer between the wheelchair seat and other surfaces such as beds, chairs, toilet sets.

There are also existing products that can be purchased separately from the wheelchair as an attachment, in order to provide elevation and transfer assistance. One such device is the Uplift Power Seat, pictured in Figure 1. This device contains a plush seat that can be raised by an electric powered actuator with a remote [8]. This is an effective device for its intended purpose of helping a person in a wheelchair get into a standing position, however it does not properly achieve the goal of transferring the user to a nearby surface, only allowing the user to stand up. Another device on the market is the wheelchair transfer board, pictured in Figure 2 [9]. The device is made of slick finished wood cut to a shape that allows safe transfer. This transfer board requires a more manual transfer as it serves as a bridge between surfaces requiring that the user uses their own strength to move across the board. This device can often be ineffective and difficult to use when transferring between two surfaces of different heights especially for users who have difficulty with manual transfer. Large transfer boards are also difficult to transport and store.

Our goal for this project is to address the limitations of existing products, in order to design a product that is low-cost (less than $250) and can be added to an existing wheelchair to provide seat elevation and transfer assistance. Specifically, this device will have the ability to elevate the user up to 6 inches vertically, while also allowing lateral sideways movement of the user. Ultimately, these functions will help to facilitate manual transfer of the user from the wheelchair to surfaces of varying heights and vice versa. These product functions should also help the user by reduce the dependence on the caregiver.

Figure 1: Uplift Premium Power Seat

Figure 2: Wheelchair Transfer Board

II. Background

Client Information

Dan Dorszynski has worked with the UW- Madison Biomedical Engineering program for a couple years. Mr. Dorszynski has muscular dystrophy and has reached out to the BME program for projects that could facilitate day to day activities. In the past, he has had projects to help him play tennis and travel on airplanes. This semester, he looks to the team to create a portable elevating and transfer seat that he could use to make the transferring process in and out of his wheelchair easier.

Relevant Biology

The final product could potentially be used by all wheelchair users, and more specifically, people with muscular dystrophy. Muscular dystrophy is a group of inheritable diseases that cause weakness and loss of muscle mass [10]. Muscular dystrophy contains thirty different genetic disorders and affects 50,000 Americans currently [11]. There are 9 major types of the disease with each disease affecting different age groups, sexes, and parts of the body. These 9 diseases, are Duchenne, Myotonic, Limb-girdle, Facioscapulohumeral, Congenital and Myopathies, Distal, Oculopharyngeal, Emery-Dreifuss, and Becker [11]. The most common in order are Duchenne, Myotonic, Becker, and Limb Girdle Muscular Dystrophy. Duchenne muscular dystrophy typically affects about one in 5,000 males at birth [10].

While there is no existing cure for muscular dystrophy, the symptoms can be minimized by various medications and therapy [12]. Steroids can be used to slow down muscle degeneration. Duchenne Muscular Dystrophy and Becker Muscular Dystrophy are very similar to each other. These disease types are linked together because both are caused by a DNA deletion mutation, resulting in a protein not being synthesized [13]. Myotonic Muscular Dystrophy affects all ages and sexes and results in the degeneration of the nervous system and heart, among other parts of the body. Individuals who have Myotonic Muscular Dystrophy tend to not be affected until later in their life. Myotonic Muscular Dystrophy is caused by a triple repeat of a gene that expands over time; more protein kinases are affected as more gene repetition occurs [14]. Finally, Limb Girdle Muscular Dystrophy affects both sexes in their young adult years. This disease causes muscular degeneration in the peripheral body parts like the arms and legs. Limb Girdle Muscular Dystrophy is a result of 9 mutations on the dysferlin gene [15].

In a general sense, Muscular Dystrophy is primarily a genetic disease, but in some cases may still be caused from genetic mutations [8]. Many of the common symptoms of muscular dystrophy include improper balance, progressive inability to walk, and muscular wasting over time [9]. This progressive inability to walk causes the individual to rely on another means of transportation, typically a wheelchair.

Wheelchair Transfer Techniques

Due to a wheelchair, people with muscular dystrophy often have to manually transfer in and out of the wheelchair seat. There are many common manual transfer techniques that exist. The most commonly used technique is the sitting-pivot transfer, which involves moving the body forward to the edge of the initial surface, placing the feet in a stable position, and placing one hand on the leading (target) surface and one hand on the trailing (initial) surface. The arm muscles are then used to pivot the body about the feet, landing in a seated position on the target surface [4]. Another technique for moving laterally on a surface is the long-sitting lateral transfer. For this technique, the legs are extended forward, the hands are placed in a comfortable position on the surface, and the user moves their body as far as they can laterally [4]. Understanding these common transfer techniques is important for determining what aspect of the transfer people most need assistance with, and thus, what features should be incorporated into an assistive device.

Product Design Specifications

The transfer and elevating seat that the team is designing should have the ability to elevate 114 kg (250lb) up to 6 inches. The product should also add no more than 5.08 cm (2 in) in height to the surface of the chair. In order to provide transfer assistance, the product should allow the user to move laterally 8.89cm (3.5 inches), relative to the location of the seat. The part of the device that is in contact with the user should fit properly while causing no pain or discomfort to the user. The device should be constructed with slick, sturdy material, such as wood with a polyurethane finish, allowing for efficient and easy transfer from one object to the other. Ultimately, these features should allow the user to move from the wheelchair to a surface at a higher elevation, without reliance upon another person. Additionally, the product must support the weight of the user, and it must not compromise the stability of the wheelchair or the safety of the user. This product is expected to be very affordable for consumers, as it will cost around $200, which is approximately 58% of what the Uplift Power Seat costs [8].

III. Preliminary Designs

Based upon the culmination of research performed and talking with the client, the three following designs were created. All the designs would use materials, such as wood or sheet metal, that are strong enough to support the weight of the user and give sufficient lateral assistance when transferring surfaces. All designs would also be safe and sturdy while raised in the air and cause no physical discomfort or danger of falling or breaking the seat to the user.

Car Jack

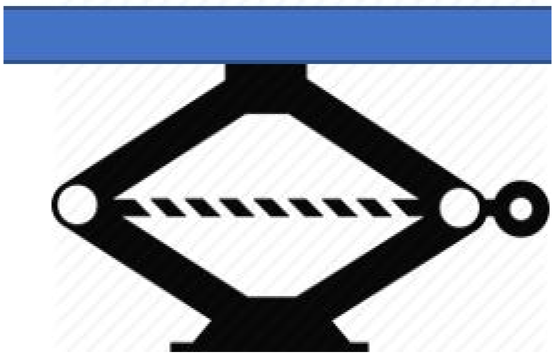


Figure 3: Car Jack preliminary design drawing

The purpose of this device is to lift the user to a desired height while supporting the weight of the user and allowing stability for transfer on and off the device. The car jack design is a simple design idea in which a manual crank car jack is placed underneath a wooden baseboard and a more comfortable seat. The wooden baseboard will be connected to the seat piece by tracks, allowing the seat to move laterally. In order for this device to be used, the user will need to turn the crank to lift himself, and turn the crank the opposite way to lower himself. In order to move laterally, the user will need to unlock tracks before use, and lock the tracks back into their resting position when finished in order to provide maximum stability while lowering himself. The car jack will be strong enough to lift the user to the required heights and will provide plenty of stability at higher heights because of the strength of the material.

Gas Spring

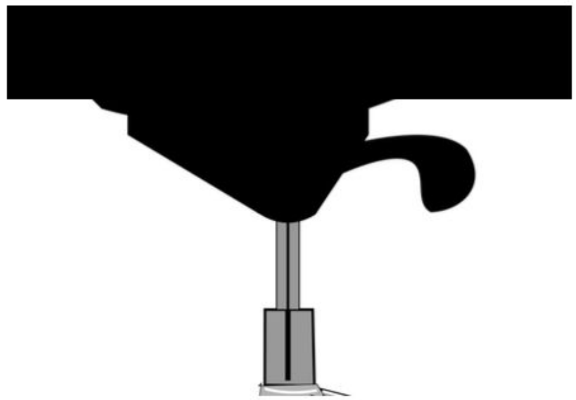


Figure 4: Gas Spring preliminary design drawing

This device would lift the user to a specific height using a pneumatic gas spring. A pneumatic gas spring design is found in many office chairs. The user will apply minimal pressure to the ground with their feet, allowing the gas spring to provide lift. The gas spring can be operated by pressing a lever attached to it. Once the desired height is acquired, the user can release the lever, locking it into place. This secures the seat into position at each height. The gas spring would sit on top of the existing wheelchair, with a platform above it to provide stability as well as a cushion for support.

Scissor Lift

Figure 5: Scissor Lift preliminary design drawing

This designs consists of a manual scissor lift that is mounted on top of the existing metal platform on the wheelchair. The top of the scissor lift would be connected to another platform made of either wood or sheet metal, with a metal track mounted on top that. Both of these materials would be strong enough to hold the 113.39 kg (250lb) weight limit given as a design constraint. The tracks, which are connected to both the platform and the scissors lift need to extend a minimum of 7.62 cm (3 inches) in order to provide the necessary lateral movement. This will be accomplished by metal guide rails that are used to move drawers. The rails allow the attack platform to slide over to help the user transfer from their wheelchair to their desired destination. Also, a cushioned seat, either bought [16],or the current one the client is using would be laid on top of the wooden or metal platform attached to the tracks. This allows the user to be comfortable while sitting on top of the device for a long period of time . A locking mechanism, either a retractable metal bar with a slot or string tying the tracks together, underneath the seat would lock the rails into place at a specific position, not allowing it to move. The rails cannot be allowed to move their maximum length because they would snap, breaking the device and injuring the user. Finally, the manual scissors lift would be operated by either a powerful drill or a ratchet. Both of these tools would require an attachment to move the scissors lift vertically. The drill would allow the lift to be raised or lowered with a press of a button, while the ratchet would require constant cranking to accomplish the same goal. Figure 1 shows an overview of the design, with the cushioned seat connected as it would during use. Figure 2 shows the concept of the slot with the metal track and retractable metal bar.

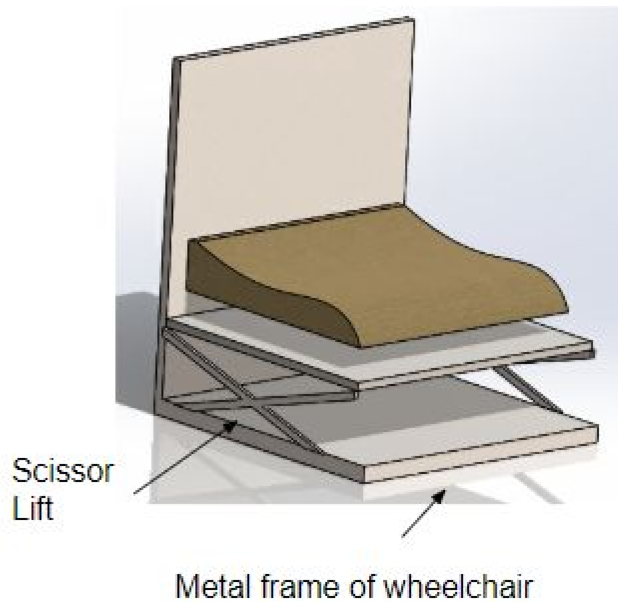


Figure 6. The scissor lift design, with a metal platform attached to the top of the scissor lift. On top of the platform is a metal track, and the base of the cushioned seat moves laterally along the track.

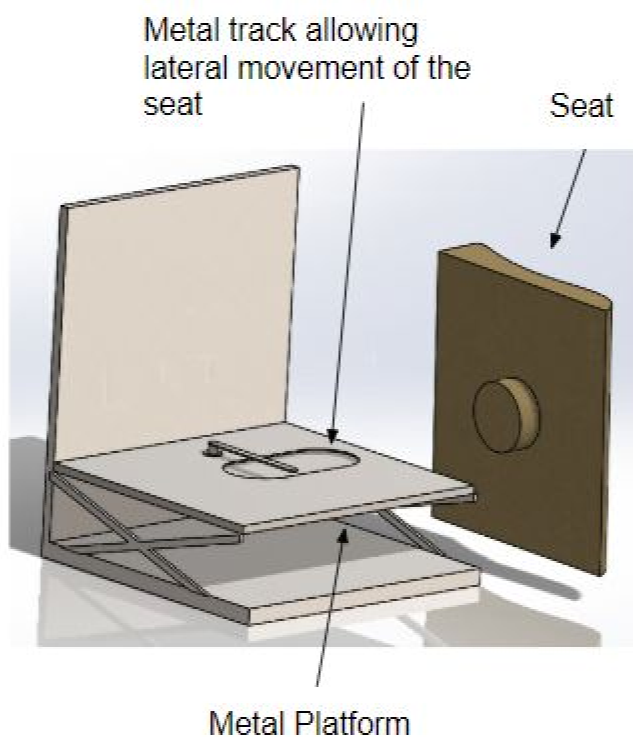
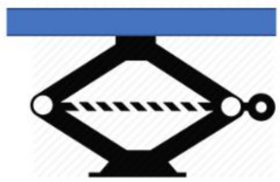
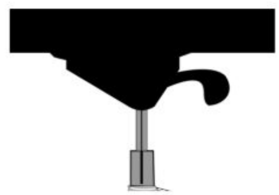


Figure 7. View of secondary metal platform with slot for a metal track. The seat is connected to a piece the can move along the metal track, when the retractable metal bar is turned.

IV. Preliminary Design Evaluation

Design Matrix

Design	Car Jack		Gas Spring/ The Office Chair		Scissor Lift	
						
Criteria (weight)						
Effectiveness(20)	4/5	16	4/5	16	4/5	16
Comfortability (15)	3/5	9	2/5	6	4/5	12
Ease of fabrication (15)	4/5	12	3/5	9	2/5	6
Ease of Use (15)	1/5	3	2/5	6	5/5	15
Durability (15)	4/5	12	3/5	9	3/5	9
Safety (10)	3/5	6	2/5	4	4/5	8
Weight (5)	1/5	1	4/5	4	3/5	3
Cost (5)	3/5	3	4/5	4	2/5	2
Total (100)	**62**			**58**		**71**

* Scores are out of 5. Displayed as score | weighted score

Table 1. The highlighted boxes indicate the highest scoring designs within each of the criteria.

Criteria

Effectiveness: This category represents how effectively the user can transfer from the wheelchair to another surface. The team believes this category should have the highest weight of 20 because the goal of the device is to make it easier for a user to transfer from a wheelchair to a new surface, which is what this category measures.

Comfortability: This category refers to how comfortable the user finds the surface of the device they sit on. The team decided to give this category a relatively high weight of 15 because the user may be sitting on the device for a long period of time, so having a comfortable surface to sit on is very important.

Ease of Fabrication: Ease of fabrication is defined as the level of knowledge and skill required to fabricate the model as well as replace any needed parts. This category is ranked fairly high because the client has requested that the product be easy to maintain at home, if it were to break.

Ease of Use: Ease of use is defined as how easy it is for the user to raise, lower, and laterally move the device. This category is ranked pretty high because if the the operation of the device is difficult or strenuous, users will likely not want to use the device as often.

Durability: Durability is defined as the ability to withstand wear and pressure. The device should be strong enough to raise and lower the patient's body weight whenever needed. The device should also be able to last a significant amount of time if it is durable. This category received a pretty high weight because the device is intended to be used indefinitely.

Safety: Safety is defined as the risk of danger presented to the user by using this device. This includes the risk of the device failing during usage and putting the user in danger. Safety is weighted at a medium level because it is important that the user is safe and does not have any risk of getting injured while using the device. However, it is not higher because the client is not too concerned over safety.

Weight: This category refers to the overall weight of the finished product. The team decided to have this category of not much concern with a weight of 5 as the overall weight of the device will not affect the ability to perform and was not mentioned as an area of much importance by the client.

Cost: This category is referring to the total price of all the materials and production of the device for the finished product. The team decided to place the category as one of the lowest in importance with a weight of 5 because cost is not much of a concern as it is predicted that, by the end of the semester, the budget of the project will not be reached.

Scoring

<u>Car Jack</u>

The Car Jack design did not end up being the most effective design the team came up with. The design preformed pretty well in effectiveness, but struggled in most of the other categories. This design received a low rating of two out of five for comfortability because it would sit quite high on the wheelchair, leading to an uncomfortable sitting arrangement for the user. The design received a high rating for ease of fabrication because it is feasible for a user to build themselves if they have the appropriate tools on hand. Next, this design received a low rating for ease of use because the user would need to ratchet themselves up with arm strength, which may be pretty difficult to do while sitting in the wheelchair. This design did pretty well in the durability category because car jacks are designed to hoist cars, which weigh much more than 113 kg (250 lbs). Therefore, lifting 113 kg (250 lbs) repeatedly should be of little problem for this design.This design did not perform well in the safety category because operating the lift with the users are muscles can be quite strenuous and possibly cause an injury. This led the team to a three out of five score for the Car Jack design in this category. Finally, Car Jacks tend to be overly heavy and relatively expensive, which could cause issues for the user with moving the wheelchair and purchasing materials. Overall, the Car Jack design did pretty well in the Effectiveness, Ease of Fabrication, and Durability categories, but struggled to stay on pace in the rest.

<u>Gas Spring</u>

The gas spring is not the most effective design idea that the team came up with. While it has a four out of five for effectiveness, this design falls short for many of the other categories. It would sit fairly high on top of the wheelchair, causing it to be uncomfortable and unsafe. The user would also have to apply some pressure to the ground in order to operate it. This might not be safe for the user's health. The ease of use is ranked low as well due to the user having to apply physical pressure with the floor. The weight and cost of this design ranked better than the other two, but this was overshadowed by the low scores on each of the other categories. Our team will keep this design and its features into consideration.

<u>Scissor Lift</u> (proposed final design)

Overall, the scissor lift rated out as the best design. It graded out as being easy to use, because it will be controlled by a button, and overall comfortable for the user to sit in. The device is expected to be effective in what it does because it starts and stops at a push of a button, allowing easier transfer positions. Concerns over the durability of the device and the cost of fabrication are issues the team will need to cope with in order to make an effective device. Durability was a concern because of all the moving parts in the design, increasing the chances of failure. Also, the cost of the actuators provides a major fiscal concern due to the fact that two large scale actuators would cut into the majority of the allotted team budget. Ease of fabrication was also rated lowly because of the multitude of moving parts in the design. If this device were to breakdown, repair would be difficult. Finally, the weight of the device was not considered an issue so the device received a moderate grade, neither helping or hurting its final score. Altogether, the scissor design in the design the team will be moving forward with due its many benefits outweighing its slight inconveniences.

V. Fabrication and Development Process

Final Prototype

The team's final prototype contained multiple different pieces of material. The manual scissors lift measured as 45.47 x 25.65 x 10.16 centimeters. The guide rails, which were connected to the scissors lift, measured 49.53 centimeters compressed, and 100.33 centimeters full extended. Without impeding the sliding the sliding length is 50.8 centimeters. The size of the cushion used measured 36.83 x 45.72 centimeters. Due to this the size of the wooden platform was cut to the same size to provide to most support possible. Four pieces of cotton string were cut to be used in the locking mechanism of the device. The two shortest pieces were cut to be 7.6 centimeters long and were used to tie the two top rails together. Two more pieces of cotton string were cut to be 20.32 centimeters long and were used to lock the distance of the rails traveled to 8.89 centimeters. The final prototype stood 11.43 cm compressed and rose to a height of 22.86 centimeters fully extended. A ratchet with an ⅜ inch drive by ⅞ inch deep socket was used to crank the scissors lift up and down.

Figure 8: Final prototype on wheelchair

Figure 9: Lateral movement of final prototype

Materials

Several materials were used in this design, but the main components included the scissor lift, the guide rails, and the plywood board.

The scissor lift, made by Extreme Max, is used as the raising mechanism in the design. This specific scissor lift was chosen because it can raise 1000 lb which is much more than the desired weight of 250 lb. Also this scissor lift fits within the budget of $250.

The 55.88 cm (22 inches) guide rails were used as the lateral movement mechanism. These specific guide rails were chosen because they have the ability to extend the 8.89 cm (3.5 inches) desired and can effectively support the weight of the user when extended based on the moment calculation seen below.

The plywood board was used as the seat of the design in which the seat cushion would rest on. The plywood board measures 36.83 cm (14.5 inch) in length and 45.72 cm (18 inch) in width, which is approximately the same size as the seat cushion. The plywood board was acquired from the stockroom in ECB and had no effect of the team's budget.

The remaining materials included the socket wrench, socket, string, C-clamps, and nuts and bolts. The socket wrench was used with a .375" in drive by .875" deep socket to raise the scissor lift. These two parts were relatively cheap and didn't make a huge affect on the budget. The cotton string was used as the stopping mechanism in the design. The string had no effect on the budget. Three 5.08 cm (2 inch) C-clamps were used to attach the scissor lift to the wheelchair. These parts have not been purchased because the scissor lift will be permanently bolted to the wheelchair if the client decides to use the design. Finally the nuts and bolts were used to attach the guide rails to the top of the scissor lift and to the plywood board. The bolts measured 0.635 cm (.25" in) dia., 0.318 cm (0.125" in) long to attach the scissor lift and 0.318cm (0.125" in) dia., 0.445 cm (0.75" in) long to attach the plywood board. These parts had no effect on the budget.

Moment Calculation

The current design consists of a seat on a lateral track, which is 55.88 cm (22 inches), that can only support 22.67 kg(50 lbs) vertically. A moment of force was calculated at the end of the 55.88 cm, getting an answer 12.67 kg*m. The client only requested 8.89 cm (3.5 inches) of lateral movement, so a ratio was used to calculate the maximum mass allowed at 8.89 cm and the answer was 142.4 kgs (314 lbs). This is over the 250 lb capacity given to the team by the client, showing that the rails should be able to support the desired weight.

Methods

In order to fabricate the final prototype the team first had to detach the top of the scissors lift from the rest of the device in order to provide enough area for holes to be drilled. Six holes, carefully marked out, were drilled into the top of the scissors lift with a push press. These holes were drilled so that screws could be screwed in to connect the guide rails and the scissors lift. The team initially tried to drill the holes in from the top of the detached platform of the scissors lift but this was met with difficulties, so instead the team drilled the holes from the bottom, achieving better results. Next the team drilled four holes into the wooden platform. These four holes were marked out so that the guide rails and the platform could be connected, without interfering with the other screwings connecting the scissors lift and the guide rails. The holes in the platform were also drilled with a push press which provided precise results. Next, the team connected the guide rail to the platform with six screws, six washers, and six nuts. Once these were connected the team attached the wooden platform to the guide rails with four screws, nuts, and washers. Once all the pieces were connected, a cushion was placed on top. The guide rails were locked together by string. To keep the guide rails from extending their full length, the two top guide rails were tied together will a simple knot. To stop the guide rails from moving further than the 8.89 cm (3.5 inches), cotton string was tied around the last guide rail and underneath the closest washer, nut, and screw sticking out of the board used to attach the guide rails to the wooden platform. Finally, a ratchet, with an attachment, and a ⅜ inch drive by ⅞ deep socket were placed on the right side of the scissors lift to allow the scissors lift to vertically. Finally the device was secured to the wheelchair using 2 in c-clamps on either side of the device to ensure it stays in place.

Testing

Hand Crank Function

The hand crank function test was used to evaluate how long it typically takes the user to elevate the scissor lift over the full height range. The test was also performed to determine many cranks the user must use to raise and lower the seat and to see what angle the user typically uses to operate the hand crank. These results can give an idea of how strenuous it is for the user to operate the hand crank. Five healthy test subjects were tested. Each subject first lowered the scissor lift to its lowest height and then set the ratchet to lift the seat upwards. The subject then tested out turning the ratchet to see what angle was most comfortable for them to use, and this angle was recorded. The seat was then moved back to the lowest position and the subject was timed while lifting the seat up 11.43 cm (4.5 inches). The number or cranks used was also recorded. This process was repeated for lowering the seat.

Lateral Movement

The lateral movement test found the amount of force it takes a user to move their weight across the seat. This movement was from the standard seat position to the transfer position of 8.89 centimeters (3.5 inches) laterally. The test would show how well that the seat can sustain the weight of the user during the transfer. Weights were added to the seat in order to retain accurate and consistent results. These weights ranged from 0 kg to 22.68 kg (50 lbs) in increments of 2.27 kg (5 lbs), and were placed directly in the middle of the seat. Then, using a Newton Force Meter, the seat was pulled the full 8.89 cm laterally. Each weight was tested five times each, and the force in Newtons was averaged from those five trials.

Results

Hand Crank Function

The results of this test are summarized in Figure 8. On average, healthy subjects use 54.4 cranks to raise the seat 11.43 cm (4.5 inches) and 12 cranks to raise the seat one inch. On average, it takes 73.2 seconds to lift the seat 11.43 cm (4.5 inches) and 62.6 seconds to completely lower the seat. We also found that users tend to use more cranks with smaller angles when moving upwards, while they use fewer cranks with larger angles while moving downwards. We believe that our device places less strain on the user, compared to when the user manually lifts themselves across a significant height gap. Without the use of an assistive transfer device, users must support their own weight using their arms as they maneuver to the target surface. While force must be applied to the ratchet to lift the seat, a mechanical advantage is provided so that the user can apply less force to lift their full body weight.

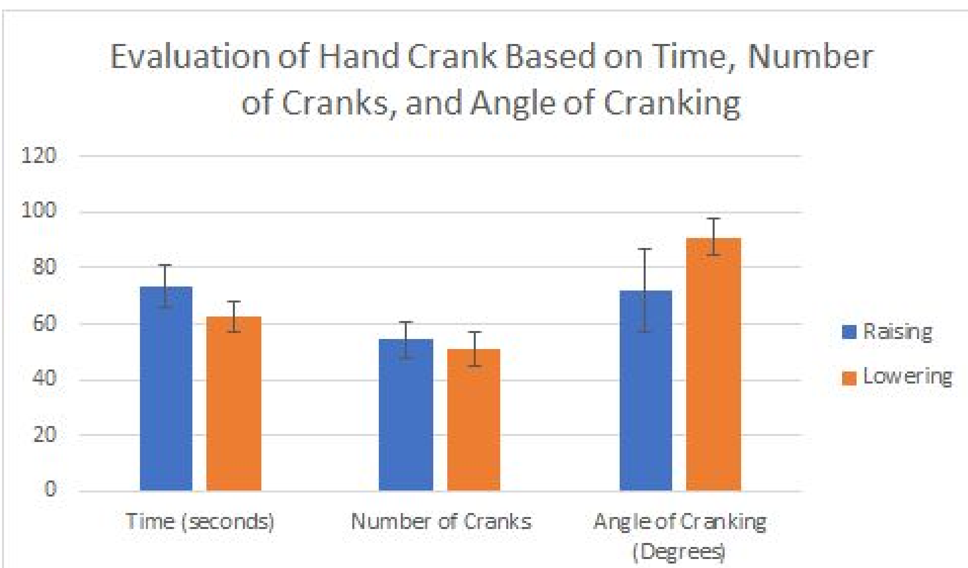


Figure 10: This graph shows the results of the test used to evaluate the hand crank function. The recorded data was number of cranks needed to reach the maximum and minimum heights, angle used to crank the ratchet up and down, and the time needed to reach the maximum and minimum heights.

Lateral Movement Test

After collecting the data, a graph shown in figure 9 was made depicting the weight (kg) vs force required (N). From this, a line of best fit was found that resulted in: y=0.294x + 2.55. The R^2 value calculated is 0.968. We believe that it is appropriate to assume a linear relationship between the weight on the seat and the force needed to pull the seat laterally; starting from rest, the minimum force needed to overcome friction along the rails will follow:

$$F = \mu_s N \tag{1}$$

Where μ_s is the coefficient of static friction and N is the normal force. μ_s should not change, so as N increases linearly, the force should also increase linearly. This test assumes that user will distribute their weight symmetrically over the seat. Using the line of best fit, it would require 35.889 N of force to move a 113.39 kg (250 lb) user 8.89 cm laterally for transfer. We believe that this amount of force is easier for a user to safely complete when compared to a device without lateral movement. The lateral movement ensures that the user will have a more safe transfer process, as it closes the gap from the seat to the desired transfer location.

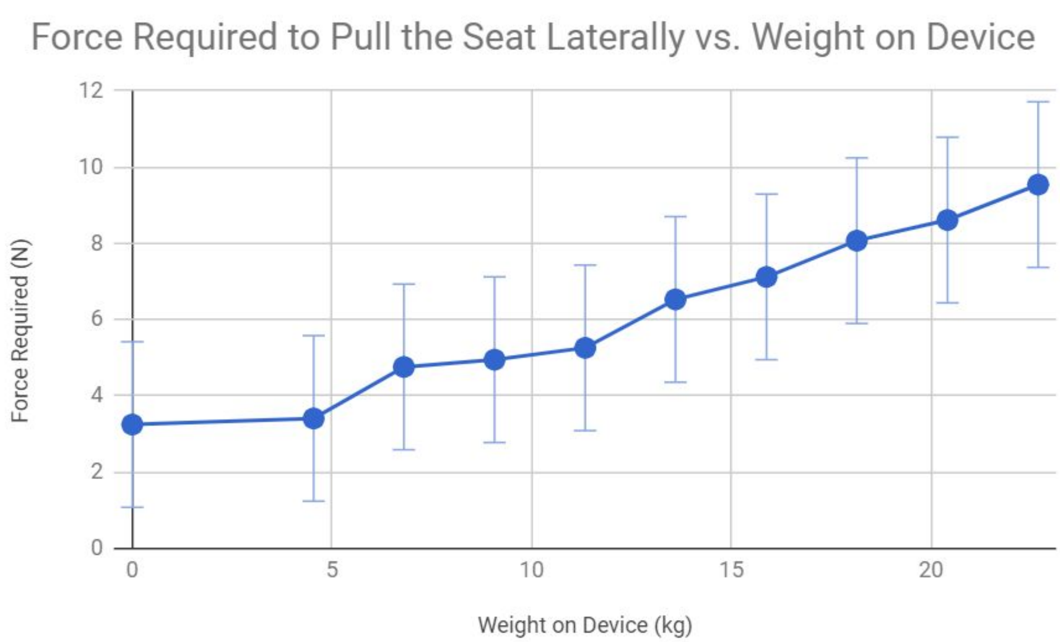


Figure 11: This graph shows the relationship between force required to move the seat laterally and the weight on top of the platform. The R^2 value is close to 1 showing the strong relationship between the data and the line of best fit. The line of best fit is the linear equation y=0.294x*+2.55

VI. Discussion

Some changes were made to the proposed final design, after it was chosen using the design matrix. One major change was made because of purchasing constraints due to the budget. The team researched electric and hydraulic powered scissor lifts, but found that these exceeded our budget. Furthermore, purchasing two linear actuators that could lift the target weight would have accounted for 80% of the budget. As an alternative solution, the team decided to purchase a manual scissor lift for the device. To operate the scissor lift, the team first tested various hand drills; however, we found that in order to achieve the necessary torque, a larger drill needed to be used [17]. Considering the potential difficulties that the user may face when transporting and operating the hand drill, we decided to focus on a different solution. Ultimately, the final device incorporates a ratchet that the user can manually crank in order to raise and lower the seat.

The final prototype met the major product design specifications. The final product fits within the dimensions of the existing wheelchair seat, so it does not interfere with moving through narrow hallways or doors. The final product can lift the seat 11.43 cm (4.5 inches), from a starting height of 11.43 cm (4.5 in.) to a maximum height of 22.86 cm (9 in.) The seat can also move up to 8.89 cm (3.5 in.) laterally. Finally, the device is able to safely raise and lower 133.4 kg (250 lbs). Ideally, the minimum height of the device would be 5.08 cm (2 in.); our final design was limited by the fact that there were no scissor lifts on the market with minimum heights of 5.08 cm. Future design modifications should focus on addressing this limitation.

Potentially, this device could be used by people with muscular dystrophy, but also by anyone who could benefit from elevation and transfer assistance. This device is beneficial for people who are traveling alone, where they cannot anticipate the heights of surfaces that they will need to transfer to (such as hotel beds and toilet seats). In this case, the device could be mounted to the wheelchair before a trip, and taken off upon returning home if the user wishes. Additionally, this device could be used in a hospital or nursing home setting. In addition to placing strain on the patient, healthcare workers experience musculoskeletal strain and injury when they assist patients with transferring [18]. For occupational and physical therapists, assisting patients with transfer was associated with 26.6% of work-related injuries [18]. For patients who have some arm strength and are not in the need of a full robotic lifting device, the team's device could be a simple solution for increasing patient independence during transfer. Additionally, healthcare providers could operate the hand crank themselves, if the patient cannot. We anticipate that operating the hand crank would be less physically taxing for the healthcare provider, compared to lifting the patient without the use of any device.

VII. Conclusions

The goal of the project was to design a wheelchair transfer assistance device that helps a user with muscular dystrophy transfer to a new surface from the wheelchair. The final design consisted of a scissor lift, guide rails, plywood board, socket wrench, and various screws and nuts. Overall, the device proved to work effectively and met the goals the team set at the beginning of the semester.

Although the device in the end met the goals stated in the beginning of the semester, there are still a few things the team would change about the design process. First off, testing with users who have limited arm strength was never done. This would be an important test to do in the future as this could give the team a more accurate gauge of how difficult it is for a person with limited arm strength to crank up the device. With these test subjects, the team would conduct similar tests to see how long it take to crank the device to the maximum height and how easy it is for them to use the lateral feature of the device. The team would also like to do further testing with the MTS machine. This machine could give the team some insight on the failure points of the device and where the device needs further support to avoid failure. Another test, this one qualitative, the team would conduct is a comfortability test. Whomever is using this device will be seated on it for long durations of time, so comfortability is important. To conduct this test the team would ask for volunteers to sit on the device. Questions regarding the cushion, the backrest, and other parts of the device would be asked and a rating system would be made so that improvement could be made.

Another part of the design process that the team would have liked to improve on was the locking mechanism to prevent the guide rails from extending too far. The device right now has a locking mechanism that consists of string attached to the guide rail and scissor lift. Although this locking mechanism meets the specifications identified earlier in the project, the team would like to find a locking mechanism that can be adjusted. This would allow for the user to stop the guide rails at shorter than the maximum extension distance and allow for easier transfer since the seat would be fixed. Therefore, more research would need to be done to see what materials could be used to accomplish this task.

Lastly, the team would have liked to find ways to make the device more automated. One place automation could be applied is in the scissor lift. Adding actuators to the scissor lift would allow for the user to raise and lower the seat by the push of the button. This was not feasible in the project with the budget given, as actuators for 250lbs cost around $300 and an automatic scissor lift for this weight costs $1,000 [19,20]. Another place automation could be added is in the lateral transfer part of the device. Making the lateral transfer motorized would again allow for less stress put on the user when transferring. The team would need to look more into this idea to see what device are on the market and if any of them would be within the budget.

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IX. Appendix A

Product Design Specifications

Portable elevating and transfer seat for wheelchair users
September 18, 2018
Advisor: Darilis Suarez-gonzalez
Team Members:

Aaron Wagner - Team Leader
Tim Madigan - Communicator
Bob Meuler - BSAC (Biomedical Student Advisory Committee)
Hayley Raj - BWIG (Biomedical Web Implementation Group)
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Function:

People who use wheelchairs are limited when they cannot elevate their seat or need assistance to transfer out of their chair. While elevating seat lifts exist, they may be expensive, and not all people qualify for this feature. Additionally, users often have to manually transfer to and from bed, chairs, and toilet seats.

The goal for this project is to address this problem by designing an affordable aftermarket product that can be added to the wheelchair. This product needs to provide seat elevation and transfer assistance.

Client Requirements:

- Device needs to fit the current wheelchair.
- Device must be able to elevate at least 15.24 centimeters (6 inches).
- Device needs to support and raise/lower 113.4 kg (250 lbs) safely.
- Device must be able to fit through doors and hallways.

Design Requirements:

1. **Physical and Operational Characteristics:**

a. *Performance requirements:* The product should have the ability to elevate the user by 6 inches. If possible, the product should also be able to lower the user by 2-3 inches. In order to provide transfer assistance, the product should allow the user to move forward or laterally, relative to the location of the seat. Ultimately, these features should allow the user to move from the wheelchair to a surface at a higher elevation, without needing help from another person. Additionally, the product must support the weight of the user, and it must not compromise the stability of the wheelchair or the safety of the user.

b. *Safety:*The device must also allow for safe movement up, down and forward along with laterally on and off of his wheelchair. The material and connections must be strong enough to support 250 lbs of weight while transferring. Finally, the device, if detachable, should be able to be removed and stored without straining or putting the user in danger.

c. *Accuracy and Reliability:* The device should be functional for a user with limited to no lower body movement and limited upper body strength. The device should be reliable and have the ability to withstand everyday use from the user without breaking down. The part of the device that is in contact with the user should fit properly while causing no pain or discomfort to the user. The device should be constructed with slick, sturdy material allowing for efficient and easy transfer from one object to the other.

d. *Life in Service:* The device should last indefinitely

e. *Shelf Life:* The device should be able to withstand multiple uses everyday with some uses coming in short succession of each other. The device should last indefinitely. Some elements may need to be adjusted if the user's needs change or upgrades for the device are designed. Depending on the design, batteries may need to be replaced along with wiring, and other small pieces of hardware.

f. *Operating Environment:* The model will mostly be used in an outdoor and indoor environment, so it needs to be able to withstand both conditions. The device will also be a part of a moving object, so it needs to be able to withstand bumps and jerks along the way. Finally, the device needs to support the weight of the user at all times when used.

g. *Ergonomics:* This device should support a weight of 250 pounds. It should be comfortable for the user to both sit in and operate.

h. *Size:* The device should be able to fit on the the seat of the wheelchair, while not being too wide or too long where it would impede the user's use of going in and out doorways. The maximum size the device can be is 20in x19in.

i. *Weight:* The device should not be too heavy where it negatively affects the speed of the chair, but it still needs to have enough weight to support the weight of the user while raising or lowering.

j. *Materials:* Components that the user will not be sitting on should be made of a material with minimal friction such as a lightweight metal or finished wood. Cushioned material should be used for any permanent seat to increase the comfort of the user.

k. *Aesthetics, Appearance, and Finish:* The device should look professional and match the rest of the wheelchair in design and comfort. It should be comprised of neutral colors.

2. Production Characteristics:

a. *Quantity: 1*

b. *Target Product Cost:* Less than $250

3. Miscellaneous:

a. *Standards and Specifications*:

FDA Code of Federal Regulations: Title 21, volume 8, sec. 890.3930 Wheelchair elevator:
Code is for: "A permanently mounted wheelchair platform lift is a motorized vertical or inclined platform lift device permanently installed in one location that is intended for use in mitigating mobility impairment caused by injury or other disease by providing a guided platform to move a person from one level to another, with or without a wheelchair."

Key Points:

- Analysis and nonclinical testing needs to show that safety controls are appropriately incorporated in order to prevent free fall of the platform if it fails
- Analysis and nonclinical testing needs to show that the device can handle the intended load with an appropriate factor of safety.
- Analysis and nonclinical testings needs to show that the device provides an adequate enclosure to prevent the user from falling off of the device.
- Analysis and nonclinical testing needs to validate electromagnetic compatibility and electrical safety

b. *Customer:* The client wants a device that can be used to elevate the wheelchair seat approximately six inches in order to help the user more easily transfer to a higher surface. The client also wants this device to be able to move laterally and distally to provide additional help for the user in transferring surfaces.

c. *User-related concerns:* The client wants the device to fit through a door with ease and to avoid any parts behind or above the head.

d. *Competition*: Current equipment on the market are too expensive even with insurance. The user believes the current products are “over designed” . Additionally, there are currently no products that can be added on to a wheelchair in order to provide elevation or transfer assistance; however, there are existing designs that integrate these features directly into wheelchair. Some examples include:

- A wheelchair design that uses cloth bands that are attached to a canvas or plastic seat. These bands are secured around the arm rests and attached to a power shaft that is mounted below the seat; the power shaft is used to shorten or length the cloth straps in order to move the seat up or down [1].
- A wheelchair design that uses an adjustable seat supporting mechanism beneath the seat, that is actuated by a hand crank. The mechanism includes foldable tubular link members that are connected to each other and can pivot in order to raise or lower the seat. The seat supporting link mechanism is directly connected to the rest of the frame of the wheelchair including other metal side supports and the front and back wheels [2].
- Carex Health Brands sells a portable lifting seat that raises and tilts in order to help the user reach a standing position. This seat is self-powered and uses a hydro-pneumatic gas spring, and it can lift up to 340 lbs; however, this product is not designed for attachment to a wheelchair specifically [3].

4. References

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X. Appendix B

Item	Description	Manufacturer	Part Number	Date	QTY	Cost Each	Total
Category 1							
Rails	Guide Rails for lateral movement	Figelli	FBA_500MM-20ZN	11/6/2018	1	$51.25	$51.25
Socket Adaptor	Adaptor for drill	Dewalt	DW2542	11/16/2018	1	$4.88	$4.88
Deep Socket	attaches to adaptor	Texton	14186	11/16/18	1	4.54	4.54
Screw Driver	Used to move scissors lift	Black and Decker	BDCS20C	11/16/18	1	14.99	14.99
Scissors lift	Main part of our design	Extreme Max	5001.5044	11/16/18	1	70.63	70.63
Category 2							
							$0.00
							$0.00
						TOTAL:	**$146.29**
						Total + Tax	$151.50

Other Materials:

- Screws
- Nuts
- Bolts
- Cotton String
- Drill Press
- Circular Saw
- Tape

XI. Appendix C

Testing Protocols

Lateral Movement Test

Purpose: To find the amount of force required to move 113.39 kg (250 lb) laterally with the seat the full 8.89 cm. This will ensure that the seat is capable of withstanding a large force.

Materials: Weights, Newton force meter.

Procedure:

1. Place weight on center of seat.
2. Hook the Newton force meter to the edge of seat
3. Pull seat out the full 8.89 cm, recording how much force was required to move the seat in Newtons.
4. Record data
5. Repeat Steps 1-4 with each incremental in weight.

Crank Test

Purpose: To find the average amount of cranks need to raise a user to the maximum scissors lift height. Angle of cranking was also taken into account as different angles results in different amounts of cranks need to reach the top. This will give the team a baseline for how much work is required to raise the lift.

Materials: Final prototype, ratchet, timer, protractor

Procedure:

1. Have user sit on top of the device
2. User begins to crank, observer starts the timer
3. Observer keeps track of time and amount of cranks it required to reach maximum height
4. At maximum height, time is stopped and amount of cranks are recorded
5. To measure the angle of the crank, the user places crank in initial angle, and then the final angle.
6. To measure the user’s descent, the user must switches the ratchet setting
7. The user begins cranking down, the observer begins to time and count cranks
8. Stop the time when the user reaches the minimum height
9. Record data
10. Repeat Steps 1-9 for each new user