Dynamic Arm

BME 200/300
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ABSTRACT

Becker's Muscular Dystrophy is a genetic disease causing atrophy of the muscle and restricting individuals from participating fully in life. This can include tasks such as eating/drinking, getting out of bed, and recreational activities. Mr. Dan Dorszynski suffers from Becker's Muscular Dystrophy, but has always loved playing tennis. The devices currently available are expensive, unsupportive, and not adaptable to Dan's specific condition. Now restricted to a wheelchair and weak upper body strength, the lack of devices to aid him in playing tennis has kept him away from his favorite sport. To cope with this he uses the momentum from his wheelchair to swing. The Dynamic Arm team has been tasked to build a device in which aids Mr. Dorszynski in his forehand and backhand tennis swing; namely, "Dynamic Arm". The team built an adjustable dynamic arm out of copper, elastic bands, and a shoulder bolt to provide him the necessary range for tennis.

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1. INTRODUCTION

1.1 Motivation

Muscular dystrophy is a disease that causes the loss of muscle mass, which can lead to the person needing assistance for everyday task such as eating [1]. Muscular dystrophy currently affects 1 in every 3500 male births which is about 20,000 new cases each year worldwide [2]. The disease can greatly affect the upper arms, so individuals suffering from muscular dystrophy often struggle to pick up their arms. Current products that help patients with this limited motion include the Euro Sling and the Willmington Robotic Exoskeleton (WREX) which are expensive and range between $5,000 to $10,000 and $2,000 to $5,000 respectively [3]. These devices help the patients carry their arms, however the high cost limits the amount of people that can access these devices to better their lives. Thus limiting the amount of people who can live independent lives which creates a sense of helpless and decreasing many individuals self esteem. An affordable alternative can lead to an increase in participation in paraplegic sports and create a more enjoyable life for paraplegics as well as their friends and families who also are affected by the situation. In the case of our client, he had specifically enjoyed playing tennis before his disease progressed. So he had asked us to make him a dynamic arm support so he could continue playing tennis.

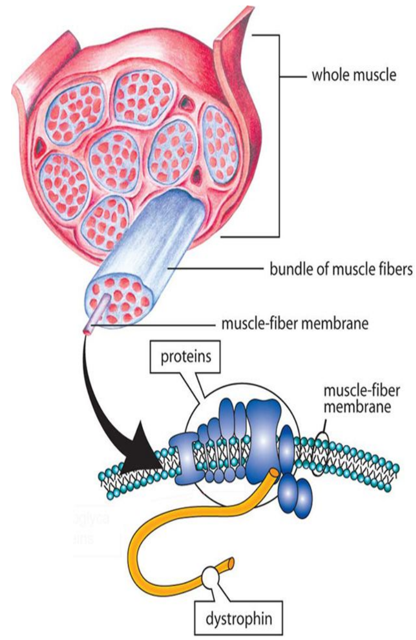
1.2 Problem Statement

In the current market, there is a lack of dynamic arm supports for quadriplegic athletes. Making it difficult for adaptive athletes to effectively participate in physical activity for extended periods of time since they often have limited range of motion or fatigue easily. Specifically for our client, who enjoys playing tennis, the rotation of his shoulder is limited so he has difficulty performing forehand or backhand swings. Our client would like us to design a mobile dynamic arm support that will allow him to use a full range of motion for forehand and backhand swings and thus improve his overall performance.

2. BACKGROUND

2.1 Biology and Physiology

Becker's Muscular Dystrophy(BMD), the form of muscular dystrophy or client is diagnosed with, is characterized by progressive muscular atrophy. Becker's is a slower progressing form of muscular dystrophy that allows patients to live into their late 40's and beyond[4]. Muscles affected include all skeletal and cardiac muscle. Skeletal muscles are used for movement and voluntary actions. Each case of muscular dystrophy is unique to the patient's body, however, typically skeletal muscles in the legs and pelvic region are affected first causing patients to be wheelchair bound. Muscular dystrophy compromises the cardiac muscle, this leads to difficulties pumping blood to the entire body, or cardiomyopathy[5]. Other symptoms include cognitive dysfunction, loss of coordination and difficulty breathing.



Figure[1]: Muscle Anatomy
Shows the cytoskeleton and extracellular matrix linked by dystrophin[6].

Furthermore there is no cure for Becker's. It is a genetic disease occurring entirely in males; reason being, Becker's is an X-linked recessive trait. Women have two X-chromosomes and if only one has the mutation in the dystrophin gene the disease will not be present, because the other chromosome can produce functioning dystrophin[6]. However, males only have one X-chromosome, so if it has the dystrophin mutation the disease will be expressed. Mutations in the gene dystrophin cause the protein dystrophin to become morphed. The protein dystrophin, as pictured in figure[1], provides a structural link between the muscles cytoskeleton and the extracellular matrix, providing structural integrity. Absence of this protein is what causes muscle atrophy[1]. Understanding the genetics and physical effects of Becker's muscular dystrophy provides insight into potential cures and a more adaptive design.

2.2 Adaptive Tennis and Physics Behind it

Adaptive tennis is a form of tennis for individuals with para(two) or quad(four) impaired limbs. By United States Tennis Association(USTA) standards, adaptations to wheelchairs are flexible. Players can make their own straps and have connections to their wheel chairs that can aid them in swinging. Unlike regular tennis, players are able to let the ball bounce twice before swinging. Furthermore, players can have a non-adaptive player toss the ball to serve; all of these facts being important when designing an adaptive tennis device[7].


Figure[2]: Dan conducting a forehand swing. Black arrow indicates the direction of the chair movement to account for the loss of lower body force. The red arrow is the incoming motion of the tennis ball.

According to B. Elliot in “Biomechanics of Tennis”, all parts of the tennis swing involve lower body flexing/tensing. Including the forehand, backhand, and serve/volley. The backhand swing also has separation rotation angles of 30° for one handed and 20° for two handed before the ball is hit. Furthermore, he concluded that players with a more effective knee flexion-extension during their serve have lower loading of the shoulder [8]. When someone is handicapped, and placed in a wheelchair, restrictions to the ideal tennis swing make playing extremely difficult. The rotation angles change and more loading is applied on the upper body. Loading can be released via movements in the wheelchair (gaining momentum by the electrospinning of the chair). As shown by figure[2] and figure[3], there is a possibility of this movement by the client; all of these facts must be taken into consideration when designing an arm to account for these additions/subtractions to a normal tennis swing.

Figure[3]: Dan conducting a backhand swing black arrow indicates the direction of the chair movement to account for the loss of lower body force. The red arrow is the incoming motion of the tennis ball.

2.3 Client Information

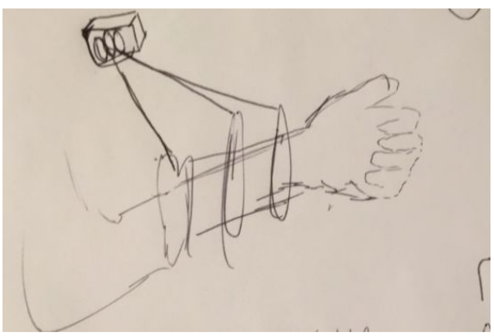
Mr. Dan Dorszynski is the team’s client and has contacted UW Madison Biomedical Engineering Department. He has worked with UW students before on the adaptive tennis grip and currently is also working on a wheelchair friendly device for airports.

2.4 Design Specification Summary

The client would prefer the final design to be aesthetically pleasing or have it be covered by a shirt. He has previously used elastic bands to aid with the movement and would enjoy it if we used bands in the design. We will have access to the battery that powers the wheelchair, so we can add electrical components to the design if need be. The main purpose of our product will be to help our client perform a forehand and backhand in tennis by supporting his arm and providing a full range of motion. The full product design specification is attached in the Appendix of this report.

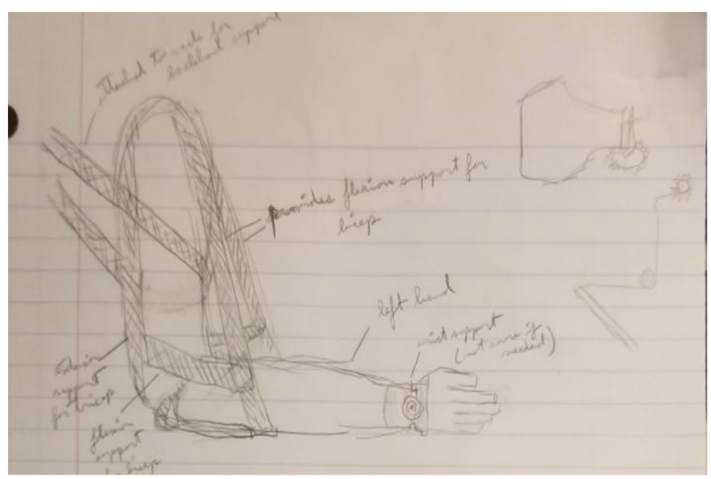
3. Preliminary Designs

The first design that we considered was the name tag idea. This design was inspired by the tensioned pulleys that one might find attached to a name tag or in a dog leash. The design involves the attachment of three tensioned pulley reels to the forearm of his left arm with three different points of contact, one at the wrist, one at the middle of the forearm, and one at the elbow. Each of these reels would connect to the right shoulder at the same point. The neutral position for this system would hold the left arm close to the chest with the hand being next to the shoulder and the elbow held bent over the stomach. The reels would provide tensioned force when pulled away from their neutral position. The rationale for this design came from the fact that our client has an easier time with downward motions than upward so we reasoned that he would be able to pull down against the tension of the reels whether he needed to do a forehand or backhand swing. This design is more so catered to improving our clients forehand swing as it assists him in moving his arm up to the neutral position which is not one he is able to do without support.



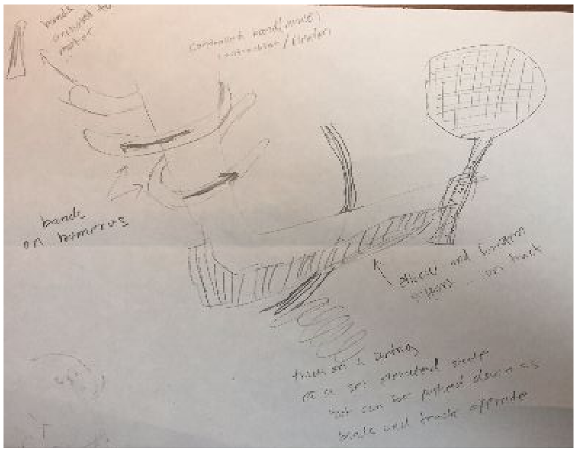
Figure[4]: Name Tag Design sketch

The second design we considered was the arm band design. This design was inspired by our client's past experience playing the cello. He was able to play the cello by suspending his hands in the air using arm bands and using the weight of his arms to pull downward as he needed.
The design would essentially serve as a modified sling which would have more flexibility than a conventional sling. The goal of the arm band design would be to hold the client's arm in a neutral position at his side with his elbow bent at an angle slightly less than 90 degrees. The rationale for this design was that if we were able to hold the client's hand at a position halfway between a forehand and backhand, the client would be able to use his shoulder muscles to move his racket in the XY plane if we were to consider the Z-axis as coming straight up of the ground.



Figure[5]: Arm Band Design sketch

The third design we considered was the track design. The track design was inspired by research conducted to identify the various muscles that are active during the action of a forehand/backhand swing. This final design is a combination of the band system and an additional spring loaded track system. Essentially, the forearm supported laterally by the bands would be further supported vertically by a track (like a rail) that is on top of a row of springs. This design capitalizes on the observation that the client has greater strength pushing down on objects than lifting. Ideally, with this design, the forearm would be supported by the track at a neutral position at the level of the chest, then if the forehand or backhand swing requires a change in racket elevation the client would be able to push down on the track to meet the ball at the correct elevation.



Figure[6]: Track Design sketch

4. Preliminary Design Evaluation

4.1 Design Matrix Criteria

Design / Criteria (weight)	Track Design		Band Design		Name-tag Design	
Comfort (20)	3/5	12	2/5	8	4/5	16
Effectiveness (25)	5/5	25	3/5	15	2/5	10
Ease of Use/installation (20)	3/5	12	5/5	20	4/5	16

Cost (10)	2.5/5	5	5/5	10	3/5	6
Adjustability (15)	5/5	15	4/5	12	4/5	12
Safety (10)	4/5	8	4/5	8	4/5	8
Total	**77**		**73**		**68**	

Figure[7] Design matrix evaluating the Track design, Band Design, and Name-tag Design on comfort, effectiveness, ease of use/installation, adjustability, and safety.

4.2 Proposed Final Design: Track

Comfort is defined as the ability of the product to be worn for long periods without the client feeling as if anything is poking or rubbing against his body. We chose this as a criterion because the device is going to be put to use in a rigorous and competitive setting. Any discomfort felt during normal activity will be exaggerated when the device is put to use in its intended setting. We gave comfort a weight of 20 because the device will be worn by our client for long hours while he is playing tennis. The product may even be put to use outside of the tennis setting. Because of the extensive amount of time that the device will be put to use, we gave comfort a high weight. We gave the name tag design the highest rating in this category because it had the least points of contact with the client's arm minimizing any rubbing or discomfort that may be caused by the designs. Because both the other designs involve strapping the client's arm into a system, they did not score as highly.

Effectiveness is defined as the accuracy with which the design will be able to increase range of motion in both the vertical and horizontal directions. This is due to the client's Becker Muscular Dystrophy, which weakens muscles associated with motion and thus limits the client's effective range of motion. We gave effectiveness a weight of 25, which is tied for our highest weight. This category was included because it is of the utmost importance that the product be able to reliably and effectively boost the user's range of motion and make tennis a more accessible sport.

Ease of Use/Installation is defined as the ability of the design to be implemented effectively. This criterion is key for our design process because it is very important to our client that the device be self-installable (client does not want to depend on too many people). Additionally, we cannot rely on the arm that needs the support to handle and install the device for use. If this criterion is not met our product will lack the effectiveness the client seeks in the device. For that reason we gave ease of use/installation a weight of 20. The Track Design received a 12/20, because the addition of the track system would require additional help for installation. The Band Design received a 20/20 because it is essentially a simple slip on sling. The Name-Tag Design received a 16/20 because it would involve hooking up multiple retractable reels before use.

Cost is defined as total expenses needed to create the product. This category received a weight of 10, which is one of the lower scores. Current mobile dynamic arm supports are very expensive so it is important we make a more economical device for the many people that cannot afford it. If this design were to be mass produced this category would receive more weight; however as of now we are only planning on creating one for our client. Our band design received the higher score because the bands are much cheaper than what is required for the other designs. Many fitness bands are under $20 so we can buy multiple bands to test and still be under the budget of the other two designs. The name tag design would require us to buy a few heavy duty retractable chains that can go for at least $50 each. The cost of the track design can be very expensive depending on the materials we choose. Since the track will be attached to wheelchair and support the weight of the arm it will have to be made of strong durable material that may be expensive.

Adjustability is defined as the amount of change we can make in our design to fit our client's needs continuously as well as conform to other adaptive tennis clients. Muscular dystrophy is a progressive disease, so it may be necessary over time to increase the amount of load the device must support to account for continuing muscle loss. Furthermore, currently only one client will use this device, but in the future it may be necessary to use the same design for other patients with muscular dystrophy. Adjustability received a score of 15 in the weighting criteria, because our main focus is to design something for our client Dan at the present time. Although it is good to think into the future, other aspects of the design are more pressing such as the ease of use and installation.

Safety is defined as how likely the patient would be able to perform the movement without being harmed. We gave safety a weight of 10 because we believe that none of these designs we will create will cause the patient any serious pain or would be dangerous. There is the possibility however, that the device can get stuck in an unwanted position and the client will struggle to get himself out that situation due to his weakened muscles. We want to consider the client's safety because this will be a medical device that he will use extensively and we want to minimize the potential for him to be injured. We gave each of these designs the same rating because none of these designs is likely to cause damage to the client. The only concern we have is that the product might get stuck in an unwanted position and the client may not have enough strength to get himself out of that situation.

Conclusion:
Our chosen design is the track. We selected this design because it would provide the most vertical support for our client's arm. We realized that vertical support was key in providing an effective design after we observed our client playing tennis. We believe that the track design promotes the greatest range of motion as it provides both strength and stability for not only the forehand, but the backhand as well. Although we did skepticize that it is hypothetically possible for the arm support to become locked into an unwanted position, we believe we can mitigate the likelihood of this happening by limiting the degree of motion of the arm support to that of an actual arm.

5 . Fabrication/Development Process

5.1 Materials

PVC Prototype:
Schedule 40 ½'' PVC (4' total)
½'' aluminum round stock
45-degree schedule 40 PVC joint
90-degree schedule 40 PVC joint
6''x 6'' Medium weight exercise band
about 6'' x 6'' -½'' aluminum plate

In the "PVC prototype" schedule 40 ½'' PVC was used because it was available, easy to cut/manipulate, and still structurally allowed us to test the prototype with our client. The 6'' x 6'' -½'' aluminum plate was used because it is rigid and can be drilled through to attach the arm to the wheelchair. The PVC joints were used because they allowed for the correct angles in which the arm is positioned as well as allowing attachment between two PVC arms. The medium weight exercise band was used based on "band test". A shoulder bolt was used so the prototype could rotate against the aluminum plate. The aluminum round stock was used because it is rigid enough to be threaded with the shoulder bolt and it has a nice contacting surface with the aluminum plate.

Copper Prototype:
JMF Copper tubing type M (3’ total)
½’’ aluminum round stock
45-degree JMF type M copper joint
90-degree JMF type M copper joint
6’’x 6’’ Heavy-weight exercise band

Note: The only thing that changed on this prototype was the copper tubing instead of schedule 40 PVC.

Along with the aforementioned materials we were graciously allowed to borrow one of Dan’s spare wheel chairs and we had access to the CoE shop which gave us short aluminum dowels and shoulder bolts which we used to fabricate our various iterations.

5.2 Methods

PVC Prototype:

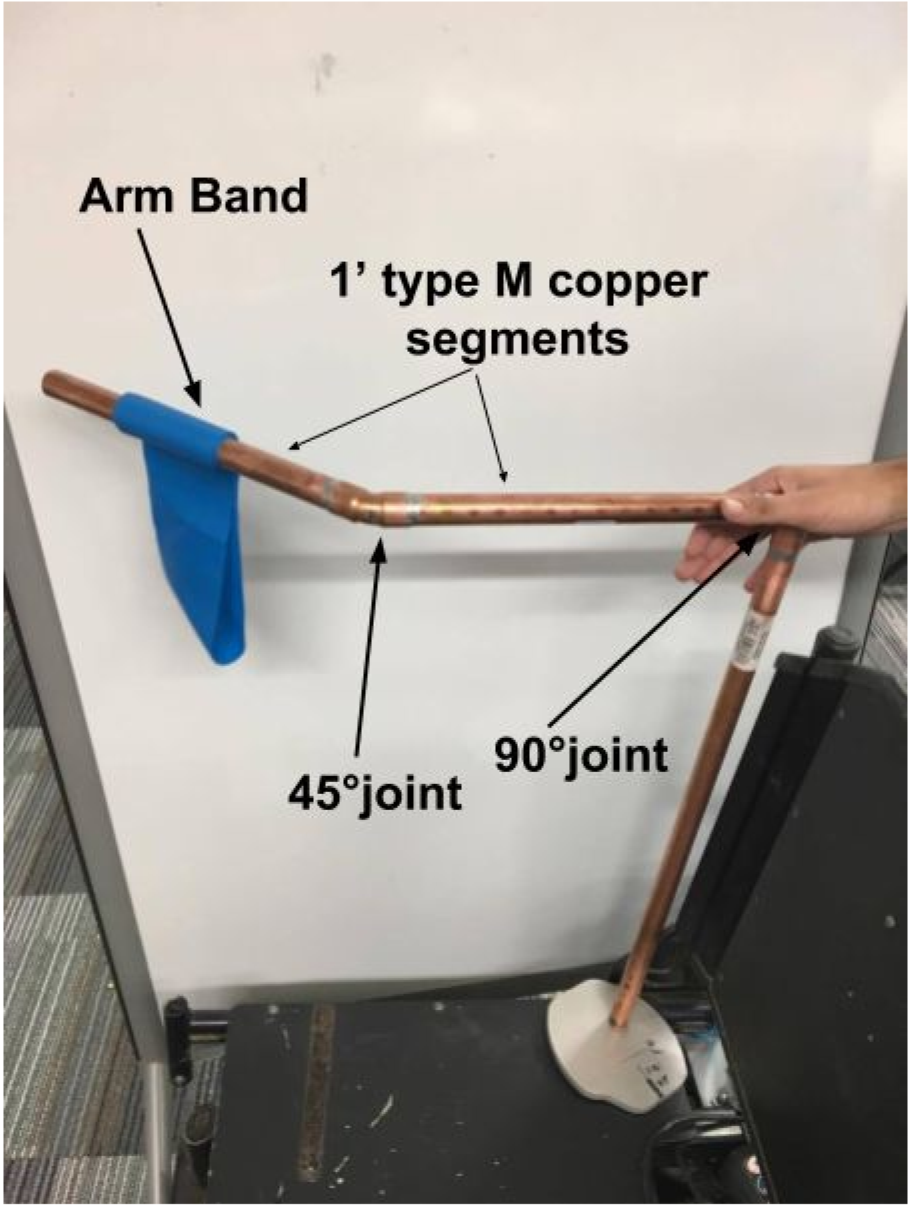
To construct the “PVC prototype” cutting the 5’ long schedule 40 PVC into 3 segments was done using a hand saw. Next, on the lathe a 2’’ piece of ½’’ aluminum round stock was turned down to a diameter .001’’ larger than the PVC inner diameter. Then tapped with 5/16-18 size. The new piece was put in freezer for 30 min. The aluminum was then press fitted into the PVC and allowed to expand. The joints were fitted together and duct tape was used for the initial stability, later replaced with PVC cement. Holes the same size as the shoulder bolt were drilled in the aluminum plate. A bolt was then placed in the hole to connect the arm to the wheelchair.

Copper Prototype:

Same procedure was followed as in “PVC Prototype”, however for press fitting a blow torch was used to expand the copper followed by the pressing of the chilled aluminum stock. The copper joints were fastened using flux, aluminum core, and a blow torch.

5.3 Final prototype

The “Copper Dynamic Arm” was the final prototype. Figure[8] pictures the copper arm segment including the attachment joints. Figure[9] pictures the attachment point to the wheelchair. Figure[10] pictures the rotary joint design; which features the press fitted aluminum stock and shoulder bolt. Copper was chosen because it is able to withstand more stress put on by our client based on observations from our client meeting. The heaviest-weight band was chosen based on data from the “Band Test”.



Figure[8]: Copper Arm Segment
Depicts the 3 copper arm segments. 2-1’ type M copper segments connected by a 45-degree joint in juxtaposition with a 2’ type M copper segment and 90 degree joint.

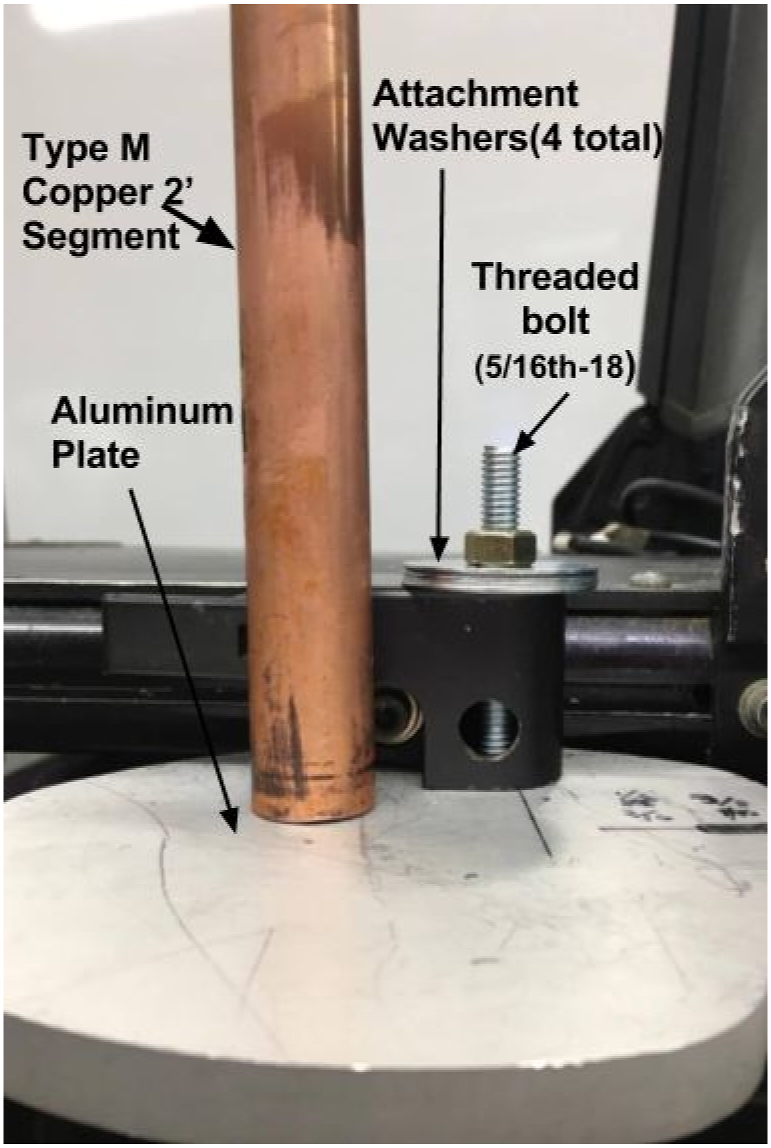
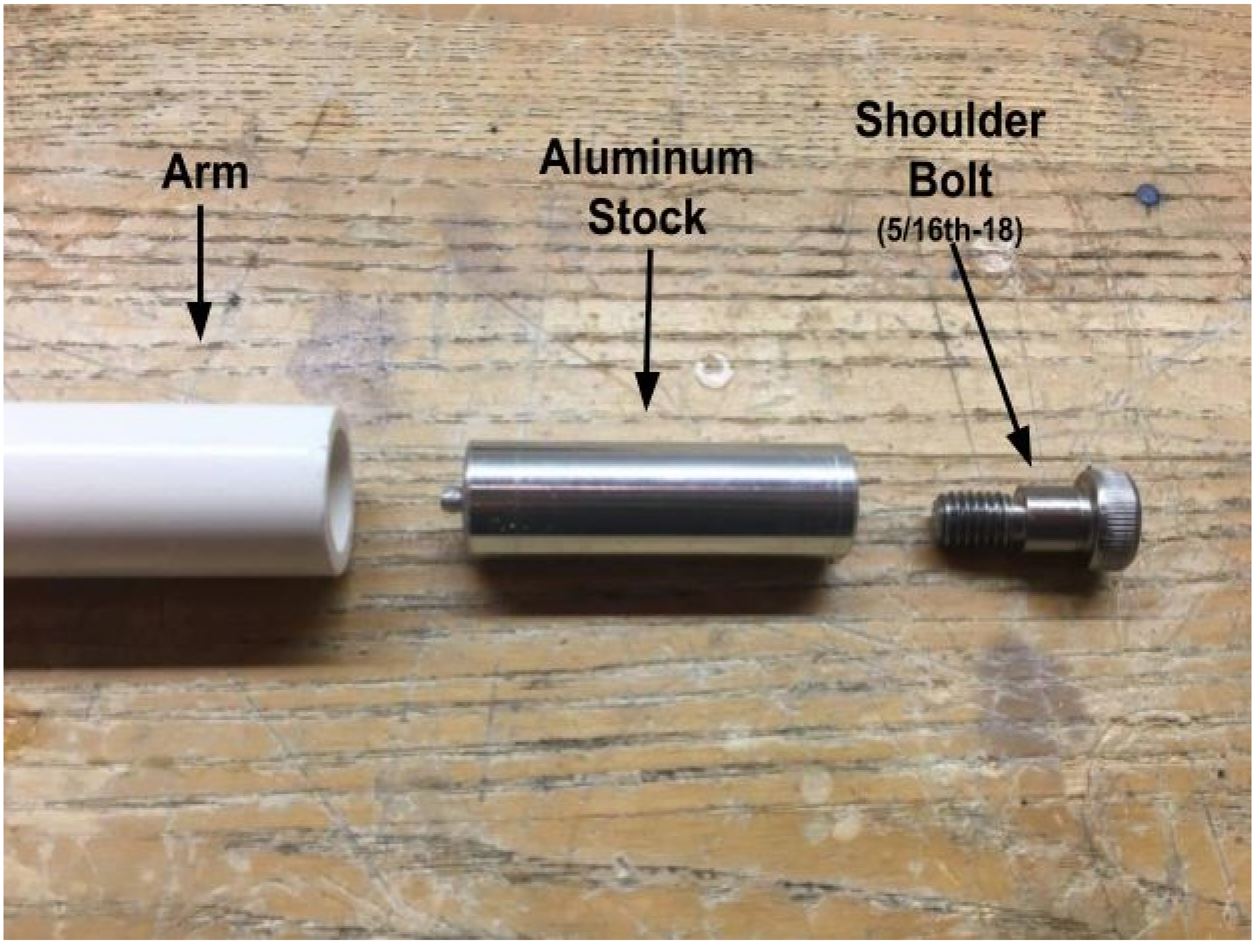


Figure [9]: Attachment of Copper Arm to Wheel Chair
Depicts the attachments site featuring the 5/16th-18 threaded bolt with attachment washers bolted through the aluminum plate. The 2' type M copper segment is a continuation of the 2' copper segment depicted in Figure [8].



Figure[10]: Rotary Joint Design
Depicts the rotary motion obtained featuring the pre-press fitted aluminum stock and shoulder bolt.

5.4 Testing

The “Band Test” was performed to understand the quality, stretch, and durability of the bands used in our final “Copper Dynamic Arm” prototype. With this information, and known client information (i.e. arm width, length, and weight), we can match a specific band to a specific client.

The PDS states “The product must be made from lightweight and durable materials that are easily acquired and not expensive”, “Must support the weight of the forearm, hand, and partial upper arm as well as tennis racket. This may include a weight of 6-11 lbs.”, “Range of motion should not be limited”, and “This device is specific to our client, but has potential to adapt to other clients.” (refer to appendix section [10.1]).

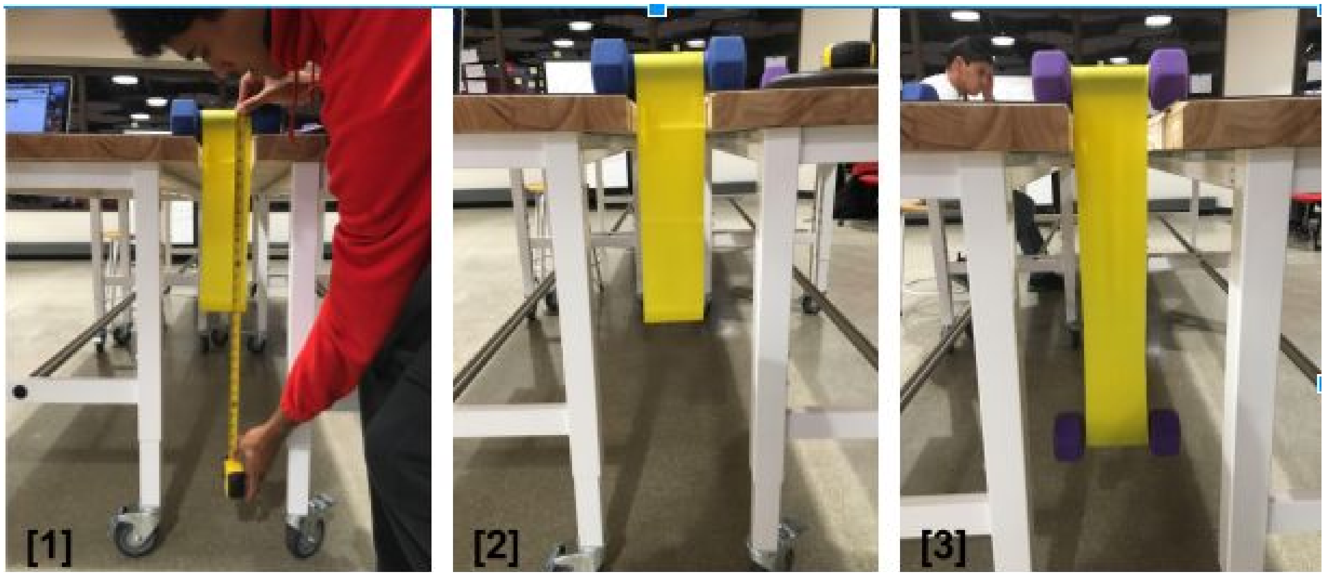
- This test was a measure of the durability of the device when analyzing the initial and ending un-stretched band length after each load applied; thus, signifying the permanent deformation of tennis playing usage over time.
- This test was a measure of the support of the device when analyzing how far the bands stretched when each load was applied; thus, signifying the arm weight of a client.
- This test was a measure of the range of motion when testing the maximum stretch; thus, signifying the maximum range of motion of the tennis swing performed by the client.
- This test can be a measure of the possible arm weights supported when graphing the change in length over weight and extrapolating; thus, signifying the potential to adapt to other clients.

Concise Protocol:

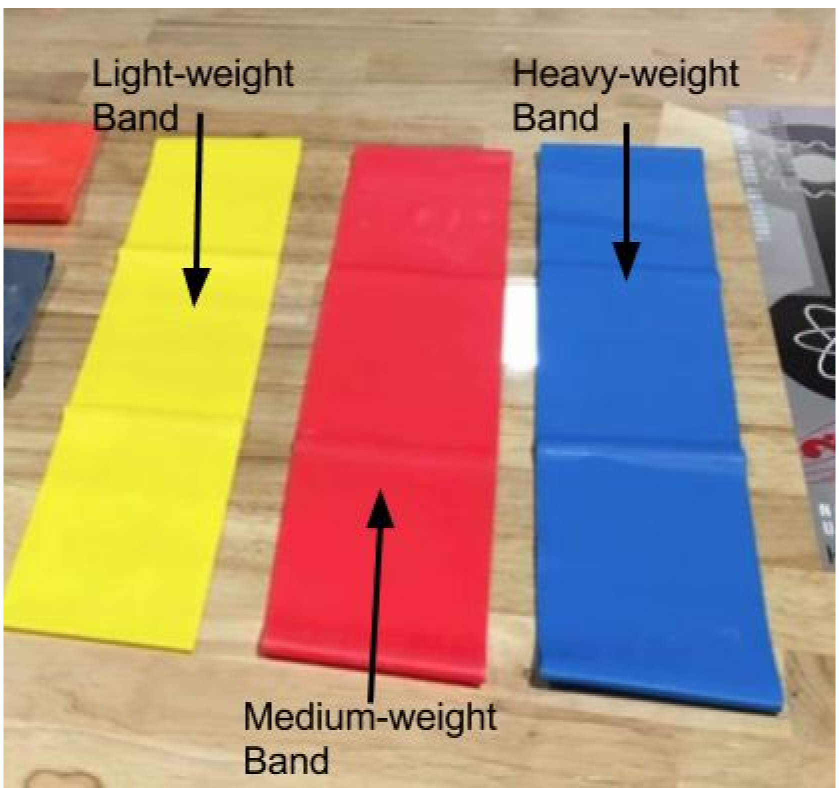
The “Band Test” was performed using 6’ resistance exercise bands, 2-5lb dumbbells, 2-8lb dumbbells, and a 12’ tape measure. The band was held by one support placed between two supporting tables. The bands used are pictured in figure[12] and the weights used are pictured in figure[13] the concise procedure is follows:

Step 1) The starting height of the band from the top down was measured. Refer to image [1] of Figure[11]. This is the Initial length of band.
Step 2) A dumbbell was then placed on the un-stretched band (pictured in image [2] of Figure[11]), and should look similar to image [3] of Figure[11]. The height from the top down was again measured.
Step 3) The weight was taken off. Then the height measured again from the top down (Refer back to image [1] of Figure[11]).
Step 4) Three repetitions at weights of 5 lbs, 8 lbs, and 2-5 lbs (10 lbs total) were conducted on each band size.

Materials used:
6’ resistance exercise bands
2-5 lb dumbbells
2-8 lb dumbbells
12’ tape measure
2 supporting tables



Figure[11] “Band Test” Depictions:
Image[1]: Depicts the top down measuring approach of an unstretched band.
Image[2]: Depicts the initial unstretched band.
Image[3]: Depicts the final stretched band.



Figure[12]: Bands used in “Band Test”
Depicts the light-weight(yellow) band, medium-weight(red) band, and heavy weight(blue) band.

Figure[13]: Weights
Depicts the dumbells used as weights in the "Band Test". 2-5 lb weights were used for 10 lb test.

Error/Variance:

One source of error could be the limited height we had for our test. Some bands stretched all the way to the floor with certain weights. It would be impossible to stretch pass the floor so a maximum change in length was prevented by the floor. If we did the testing from a higher height then there is a chance that the bands would have stretched a lot more. This can lead us to believe that a band will not stretch as much as it actually will.

Expectations:

The team expects the bands to go back to their initial unstretched length. Furthermore, expectations are made that the heaviest(blue) band will stretch the least, and lightest(yellow) band will stretch the most. The team expects the largest permanent deformation to occur in the lightest band. The results should measure the durability, support, and range of motion of the band aspect to our "Copper Dynamic Arm" prototype.

6. Results

The below statements are the evaluation of how well the durability, support, and range of motion of the bands in the "Copper Dynamic Arm" preformed. All information concluded is based on calculations performed that are shown and explained in appendix section [10.4]. Note: All Raw data in appendix section [10.3].

Results of durability aspect of band test:

Take the final unstretched length and subtract the initial unstretched length of each trial. This gives the amount of permanent deformation of the band, over the two trials when looking at the last trial. Refer to Example Calculation[1] in Appendix [10.4]. Based on this data, the team concluded the lightest-weight(yellow) band deformed the most at 0.5625 in; meaning, it is the least durable band. The heaviest-weight(blue) band showed the least deformation at 0in. So, if used for a long time, the blue band should be the band used in our final design.

Results of support aspect of band test:

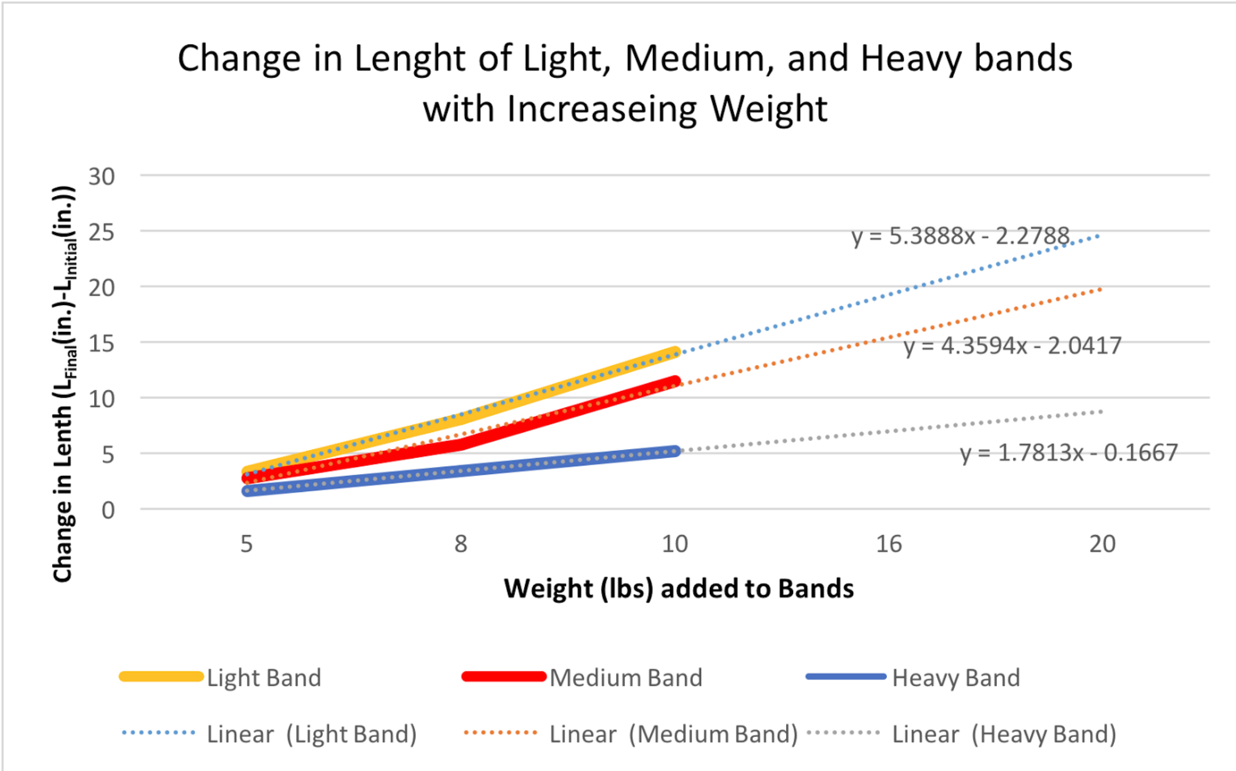
Subtract the final stretched length by the initial stretched length. Refer to Example Calculation [2] in Appendix [10.4]. The team concluded that the most supportive band is the heaviest-weight(blue) band.

Results of range of motion aspect of band test:

Refer to the maximum stretch i.e. final stretched length of each trial. Refer to Example Calculation [3] in Appendix [10.4]. Since the blue band was most fitting to our client (most durable and supportive), the team concluded that the range of motion needed to be analyzed especially with respects to the blue band. The maximum stretch of the blue band at 10lbs was **5.1875in** and the extrapolated 16lbs was **28.3341in;** showing, range of motion was not restricted.

Results of possible arm weights supported aspect of band test:

Graph the change in length of the bands (i.e. same calculation as the support). Refer to Example Calculation[4] in Appendix [10.4]. Linearly fit a trend line to each curve graphed. Plug in the weight to the "x" value and compute the equation. The "y" value is the extrapolated change in length. Conclusions can be made from this data for example. At a 18lb arm the yellow band stretched above its maximum failure stretch at **67.7087 in.** Refer to figure[14] below.



Figure[14]: Graph of change in length of light, medium, and heavy bands while increasing weight. Change in length of light, medium, and heavy bands with increasing weight and extrapolation up to 20lbs.

7. Discussion

Our final prototype provided the necessary support our client required. It was able to hold up his arm at his requested height and was able to move his arm in the horizontal and vertical planes. The copper design is more durable than the PVC design as it did not bend while in use. While this design is a lot better than our PVC prototype it still needs some work. Our client was able to move his arm in the vertical plane but was not able to achieve the full range of motion as he does not have enough strength to move his arm that much. The copper design is heavier than the PVC which makes it harder for our client to move. The engineering team overestimated the strength in his arm and used a material that was too heavy for him to move for an entire length of a tennis match.

8. Conclusion

Mr. Dan Dorszynski suffers from Becker's Muscular Dystrophy and is in need of a device to aid his forehand and backhand swing in one of his favorite sports, tennis. The team has been tasked with designing this device that is supportive, non restrictive, and gets him back on the court. The final design consist of three copper bars blow torched together and attached to a base plate on the wheelchair through a shoulder bolt. There is also an elastic band on the copper bar which will support Mr. Dorszynski arm.

Most of the teams emphasis and concern was on supporting our clients arm and not so much on how much strength he has to move his arms in the horizontal direction. This emphasis guided us to make a final design that supported his arm well but was difficult for him to move after a few swings. If the team were to do this all over again we will have a more holistic approach in order to satisfy all of our clients requirements instead of just one. In the future the team will work on making the design lighter, more adjustable, and easier to transport. A functional product has the potential to help the lives of thousands of people who struggle to hold up their arms and need some extra support for everyday task.

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10. Appendix

10.1 Product Design Specification

Function:

The function of our product will be to provide mobile arm support for people who have difficulty picking up their arms. This product will be ideal for people who suffer from muscular dystrophy, since it may allow them to perform everyday task such as give handshakes and hugs. Our client specifically wants to use this device to compete in quadriplegic tennis tournaments in order to better perform a forehand and backhand swing.

Client requirements:

- The client does not want us to limit ourselves in terms of designs and said that everything will be fair game.
- The final design would ideally be covered by a shirt, in order to improve the aesthetics.
- The client suggested using bands since he has used bands before to help him move his arms, although he said they are not required.
- The client moves around in an electric powered wheelchair so we have access to a 24 volt battery to power electrical components if need be.
- The focus of this design will be to allow the client to perform a forehand and backhand in tennis by supporting his arm and providing a full range of motion.

Physical and Operational Characteristics:

a. *Performance requirements:* The product must provide enough support to the arm so the client can easily pick up his arms without becoming fatigued by the end of a game, which in average runs around an hour to two. The design should also allow him to swing his arms in a full range of motion. Our client should be able to put on and take off the final product by himself, or with minimal assistance.

b. *Safety:* The product must be free from any sharp or jagged edges and rough surfaces that may cause cuts and abrasions. Also it must not lock in any positions or cause hyperextension. There should be a minimal chance of injury. As in, little to no chance of pinching or twisting that could lead to increased levels of discomfort or worse physical damage to the user.

c. *Accuracy and Reliability:* The product must conform to the motions of the client. It must not over or under exaggerate the client's intended motion. As well as it should not impede the user's desired motion in anyway, it must only add to the user's range not limit it. And above all the device must be consistent

d. *Life in Service:* The product must be able to be used for at least 5 years with the frequency that the client specified. Repairs should also be easy to make.

e. *Shelf Life:* The product must be able to be stored for 6 to 12 months without use in the case that the client is unable to compete in any tournaments for that time.

f. Operating Environment: The product's operating environment is on a tennis court. In this environment the product could be exposed to high temperatures and humidity.

G. Ergonomics: The client is able to push down but is not able to raise the arm. The product must support the client's arm in raising the arm and swinging. The client prefers to have something that is simple and self-installable. There is also a need to establish an elevated position as the default position since that state requires the most effort to achieve by our client.

H. Size: The client prefers to have a device which will not prove to be cumbersome. It needs to be as minimal in size as possible. If the size of the device extends too far it will get in the way and fail at being an effective aid for our client.

I. Weight: The product must be light enough for the client to self-install. Our client travels and participates in tournaments so a lightweight device that can be easily handled is ideal. Having a light weight product will allow for a more efficient transfer of support thus minimizing cost and ware on the device.

J. Materials: The product must be made from lightweight and durable materials that are easily acquired, ultimately not expensive.This is to ensure the client will be able to benefit from the device for a long period of time as well as being able to acquire replacement parts for as low of price as possible.

K. Aesthetics, Appearance, and Finish: The product must be able to provide a benefit for the client while still being sleek enough so that motion is not inhibited as well as allowing for our client to not feel embarrassed by the device.

Production Characteristics

a. *Quantity:* At present, the quantity required is simply one with the possibility to be able to adapt the design to accommodate a larger demand. Consideration to expand the device to support both arms is also being considered.

b. *Target Production Cost:* No target production cost was established so instead the target is to be kept as low as possible. No target price was established due to the fund set aside to cover projects whose clients experience a handicap.

Miscellaneous

a. *Standards and Specifications:* FDA approval is not needed for this device. Adaptive tennis rules and regulations do not interfere with the design of this device. It is allowed to be electronic, mechanical, and/or mounted to the wheelchair.

b. *Customer:* At the present moment our only customer is our client. This device is specific to our client, but has potential to adapt to other clients. Customers then would include any adaptive tennis players, specifically those with Becker's muscular dystrophy. The device may also serve useful for customers who are not adaptive tennis players but still have a limitation in arm strength.

c. *Patient-related concerns:* The device must be able to suit a fore and backhand stroke. It must also support the weight of the forearm,hand, and partial upper arm as well as tennis racket. This may include a weight of 6-11 lbs. Range of motion should not be limited by the device.

d. *Competition:* Currently, no design for adaptive tennis supports are on the market. In 2016/17 a UW Madison BME design team made an adaptive tennis grip. Adaptation such as leg and lower body supports are sold and can be considered.

10. 2 Materials and Expenses:

Item	**Description**	**Manufacturer**	**Part Number**	**Date**	**QTY**	**Cost Each**	**Total**	**Link**
Power Band	big rubber loop	Gold's Gym	05-0818GG	10/28/2017	1	$15.77	$15.77	Walmart
Stretch Kit	long stretch bands	Gold's Gym	05-0900GG	10/28/2017	1	$9.27	$9.27	Walmart
Stretch Loop	short strech loops	Gold's Gym	05-0837GG	10/28/2017	1	$8.97	$8.97	Walmart
3" lazy susan	square with hole	Dorn hardware	539363	11/7/2017	1	$3.29	$3.29	True Value
2" swivel plate	ball bearing wheel	Dorn hardware	174557	11/7/2017	1	$4.29	$4.29	True Value
2" rubb whl	socket with wheel	Dorn hardware	574582	11/7/2017	1	$6.99	$6.99	True Value
Copper Tubbing	piping	Dorn hardware	94913030018	11/24/2017	2	$2.92	$5.84	Mills Fleet/ Farm
Copper Tubbing	piping	Dorn hardware	94913030100	11/24/2017	2	$5.05	$10.10	Mills Fleet/ Farm
Elbow	copper joint	Dorn hardware	94913590475	11/24/2017	2	$1.55	$3.10	Mills Fleet/ Farm

Elbow	copper joint	Dorn hardware	94913535223	11/24/2017	1	$0.35	$0.35	Mills Fleet/ Farm
Elbow	copper joint	Dorn hardware	94913290221	11/24/2017	1	$0.90	$0.90	Mills Fleet/ Farm
3/4" PVC Elbow	pvc elbow	Dorn hardware	6896506	12/2/2017	1	$0.67	$0.67	True Value
3/4" X 12" riser	pvc tube	Dorn hardware	6901323	12/2/2017	4	$1.39	$5.56	True Value
1/2" 90 degree el	pvc joint	Dorn hardware	6896980	12/2/2017	1	$1.56	$1.56	True Value
1/2" X 12" riser	pvc tube	Dorn hardware	6901310	12/2/2017	2	$1.09	$2.18	True Value
1/4 sheet sndppr	60gr Sand Paper	Dorn hardware	2368111	12/2/2017	1	$1.47	$1.47	True Value
1/2" 45 deg elbow	pvc joint	Dorn hardware	6896496	12/2/2017	3	$0.46	$1.38	True Value
1/2" 90 deg elbow	pvc joint	Dorn hardware	6896467	12/2/2017	4	$0.28	$1.12	True Value
3/4" X 18" riser	SCH 80 pvc	Dorn hardware	6901326	12/2/2017	1	$1.99	$1.99	True Value
1/2" X 24" riser	SCH 80 pvc	Dorn hardware	6901318	12/2/2017	1	$1.73	$1.73	True Value
3/4" thd cap	made of pvc	Dorn hardware	6890774	12/2/2017	1	$2.80	$2.80	True Value
3/4" thd coup	made of pvc	Dorn hardware	6890737	12/2/2017	1	$3.05	$3.05	True Value
5/16X 1/1/2 wash	fender washer	Dorn hardware	2329555	12/2/2017	1	$3.69	$3.69	True Value
long prg T nut	5/16 X 3	Dorn hardware	2012669	12/2/2017	1	$0.49	$0.49	True Value
1/2" X 5' tube	SCH 40 pvc	Dorn hardware	6898504	12/2/2017	1	$1.46	$1.46	True Value
5/8" X "48"	poplar dowel	Dorn hardware	2152030	12/2/2017	1	$1.99	$1.99	True Value
7/8" X 36"Dowel	oak	Dorn hardware	2152172	12/2/2017	2	$3.78	$7.56	True Value
1/2" X 18" riser	SCH 80 pvc	Dorn hardware	6901317	12/2/2017	1	$1.39	$1.39	True Value
3/4" 90 deg el	pvc elbow	Dorn hardware	6896981	12/2/2017	1	$1.79	$1.79	True Value

5/16 -18 X 3	Tap bolt	Dorn hardware	2028355	12/2/2017	3	$0.49	$1.47	True Value
5/16-18	hex nut	Dorn hardware	2028023	12/2/2017	3	$0.29	$0.87	True Value
5/16 insert	wooden	Dorn hardware	2025258	12/2/2017	2	$0.59	$1.18	True Value
5/16 X 1-1/2	hex bolt	Dorn hardware	2325009	12/2/2017	1	$1.09	$1.09	True Value
						Total:	**$115.36**	

10.3 Raw Data from "Band Test"

Band Testing						
Type of Band	**Trial**	**Weight(lbs)**	**Change Length (in)**	**Initial(in)**	**Final(in)**	**Average(in)**
Light-weight (Yellow)	1		3.3125	16.4375	19.75	
	2	5	3.3125	16.4375	19.75	**3.3125**
	3		7.9375	16.4375	24.375	
	4	8	8.25	16.625	24.875	**8.09375**
	5		12.625	16.75	29.375	
	6	10	15.5625	16.9375	29.5	**14.09**
	7	16	x	x	x	
	8	16	x	x	x	**x**
	9	0	0.5625	16.4375(beforeTesting	17(afterTesting)	
Medium-weight (Red)	1	5	2.8125	16.125	18.9375	
	2	5	2.75	16.25	19	**2.78125**
	3	8	5.6875	16.3125	22	
	4	8	5.8125	16.3125	22.125	**5.75**
	5	10	11.625	16.3125	27.9375	
	6	10	11.375	16.625	28	**11.5**
	7	16	x	x	x	
	8	16	x	x	x	**x**

	9	0	0.5	16.125	16.625	
Heavy-weight (Blue)	1	5	1.625	16.5	18.125	
	2	5	1.625	16.5	18.125	**1.625**
	3	8	3.375	16.5	19.875	
	4	8	3.375	16.5	19.875	**3.375**
	5	10	5.25	16.5	21.75	
	6	10	5.125	16.5	21.625	**5.1875**
	7	16	x	x	x	
	8	16	x	x	x	**x**
	9	0	0	16.5	16.5	

10.4 Example Calculations for Results Section:

Durability Calculation:

Example calculation [1]:

(ending un-stretched length – Beginning un-stretched)
17.00(in.) – 16.4375(in.) = **0.5625 (in.)**

Data from light-weight band

Support Calculation:

Example calculation [2]:

(final stretched length – initial un-stretched length)
19.75(in.) - 16.4375(in.) = **3.3125 (in.)**

Data from light-weight band trial 1

Range of Motion Calculation:

Example calculation [3]:

Final Stretched length of Trial 5 light-weight band =**29.375 in**.
Trial 6 light-weight band = **29.50 in.**

Data from light-weight band

Possible Arm Weights Supported Calculation:

Example Calculation [4]:

Yellow: y=5.3888x-2.0417 at 18lbs
y=5.3888(18)-2.0417= **67.7087 in.**

Blue: y= 1.7813x-0.1667 at 16lbs

y= 1.7813(16)-0.1667= **28.3341 in.**

Data from light-weight band and heavy-weight band