Dynamic Arm

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ABSTRACT

Duchenne 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; including tennis. Mr. Dan Dorszynski suffers from Duchenne Muscular Dystrophy, but has always loved playing tennis. The devices currently used are expensive, un-supportive, 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. 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". His swing now uses momentum from his chair and the team's further testing should show the exact force needed to be generated by the Dynamic Arm. Currently focused on the Track design, the team hopes to contribute and get Dan back on the court.

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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 [5]. Muscular dystrophy currently affects 1 in every 3500 male births which is about 20,000 new cases each year worldwide [1]. 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 [6]. 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. This leads to the need of outside help to perform everyday task and can make the patients feel helpless. Our client specifically enjoyed playing tennis before his disease progressed so he would like us to make him a dynamic arm support so he may continue playing tennis.

1.2 Problem Statement

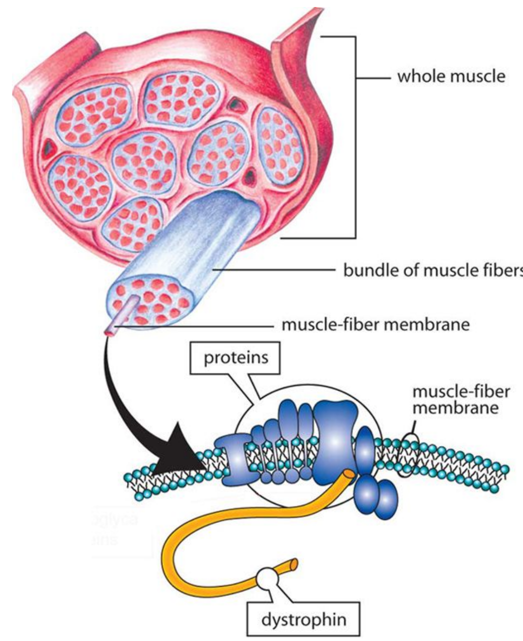
Currently there are no dynamic arm supports for quadriplegic athletes. This makes it difficult for adaptive athletes to use their full potential since they have limited range of motion or fatigue easily. Specifically, the rotation of his shoulder is difficult so he can not perform forehand or backhand swings. Our client wants us to design a mobile dynamic arm support that will allow him to use a full range of motion for forehand and backhand swings.

2. BACKGROUND

2.1 Biology and Physiology

Becker's Muscular Dystrophy(BMD) is characterized by progressive muscular atrophy. Not to be confused with the more severe Duchenne muscular dystrophy, Becker’s is slower progressing and allows patients to live into their late 40’s and beyond[2]. 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. The heart is the main cardiac muscle, and when affected by muscular dystrophy leads to difficulties pumping blood to the entire body, or cardiomyopathy[4]. Other symptoms include cognitive dysfunction, loss of coordination and difficulties breathing. Patients with Becker’s muscular Dystrophy usually live well into their 40’s and beyond[3].

Furthermore there is no cure for Becker's and 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.[7] 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(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[2]. Understanding the genetics and physical effects of Becker's muscular dystrophy provides insight into potential cures and a more adaptive design.



Figure[1]: Muscle anatomy showing the cytoskeleton and extracellular matrix linked with dystrophin.[8]

2.2 Adaptive Tennis and Physics Behind it

Adaptive Tennis is the sport tennis tending to individuals with para(two) or quad(four) limbs impaired. 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 hit 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 swing.

According to B. Elliot in "Biomechanics of Tennis", all parts of the tennis swing have lower body flexing/tensing involved. This includes 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 was associated with lower loading in the shoulder. [8]. When someone is handicapped, i.e. by being 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). Pictured in figure[10.2.1] and figure[10.2.2] in appendix section [10.2], 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.

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 two help our client perform a forehand and backhand in tennis by supporting his 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 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 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 backhand swing as it assists him in moving his arm up to the neutral position which is not one he would be able to do without support.

The second design we considered was the arm band design. This design was inspired by our clients past experience with playing the cello. Our client 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.

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.

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[2] 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 criteria 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 limiting 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 users range of motion and make tennis an easier sport.

Ease of Use/Installation is defined as the ability of the design to be implemented effectively. This criteria 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 criteria is not meet 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 can not 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 but multiple to test out and still be under the budget of the other two. The name tag design will 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 can be expensive.

Adjustability is defined as the amount of change we can make in our design to fit our patients needs continuously as well as conform to other adaptive tennis clients. Muscular dystrophy is a progressive disease, so it may be necessary 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 patient's safety because this will be a medical device that the patient will use extensively and we want to minimize the potential for the patient to be injured. We gave each of these designs the same rating because none of these designs can cause damage to the client. The only concern we have is that the product can get stuck in an unwanted position and the client will not have enough strength to get himself out of that situation.

5. Fabrication/Development Process

5.1 Materials

The materials will consist of multiple springs, ball bearings tension bands, wood/metal/plastic rods, along with other equipment that is offered to us through the COE shop. The rods along with the ball bearings will be utilized to create a track upon which the arm will be strapped to. The springs will lie beneath the track and provided the ability to target the ball at different elevations.

5.2 Methods

In order to make the prototype we will need to first look through the spare materials in the back of the COE shop and then determine what materials will need to be ordered. We will then fabricate our design using a mixture of woodworking and metalworking techniques.

5.3 Final prototype

Our final prototype will consist of a track (made out of two curved plastic/metal/wood rods), ball bearings, an arm strap, and a band. The track will have a neutral position at chest level.

5.4 Testing

As of now we have not done any testing because we have not had the chance to start on our prototype yet.

However, we do plan to conduct the following tests:

1.) Rest arm on track and measure for ideal elbow height

2.) Test resistance of track by measuring force needed to move arm from side to side while strapped in
3.) Weigh track system

6. Results

At this time we have not conducted any tests because we do not have a finished prototype. Results will be reported as soon as data is obtained.

7. Discussion

After we complete our product, we will be able to determine if our clients range of motion significantly increases, and if he is strong enough to successfully perform forehand and backhand swings. If our results indicate that the design successfully allows our patient to play tennis the product has the potential of helping many people. However, before it can be released to anyone a lot more research would be conducted to determine its overall effects on the user. In the future, the team will add more functions to the track or even add a second track to aid in the movement of the other arm. The application of the track can help thousands of people who suffer from muscular dystrophy and other illnesses that inhibit motion.

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.

So far, the team has narrowed five designs into three and rated them using the design matrix pictured in figure[2]. The Track Design was the winning design in the matrix, and is also chosen to move on to the fabrication process. The team has started fine tuning the Track Design by creating computer generated images including dimensions and materials. Fabrication planning is also underway.

The next steps the team must do is preliminary testing and data collection as well as begin overall fabrication. Testing may include band resistance strength testing in order to conclude the total weight the band component of the design can take. Backhand/forehand range of motion measurements may be conducted using a motion detector. Furthermore, mass measurements may be taken of the client's arm and biceps.

In the future, the team hopes to have a working prototype that allows dan to test it playing tennis at the local gym.

9. References

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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

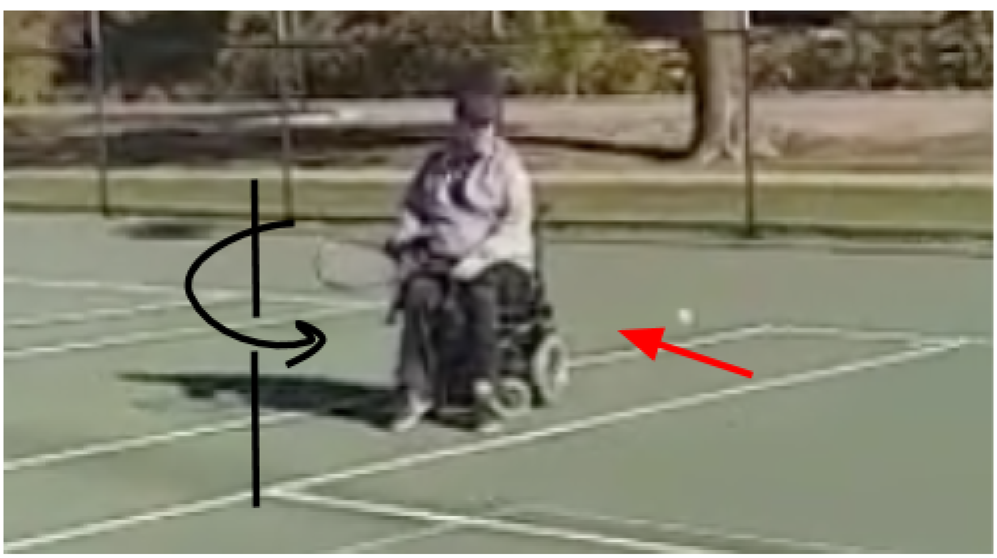
a. *Standards and Specifications:* FDA approval is not needed for this device. Adaptive tennis rules and regulations do not interfere with the design of this device. It is allowed to be electronic, mechanical, and/or mounted to the wheelchair.

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. Adaption such as leg and lower body supports are sold and can be considered.

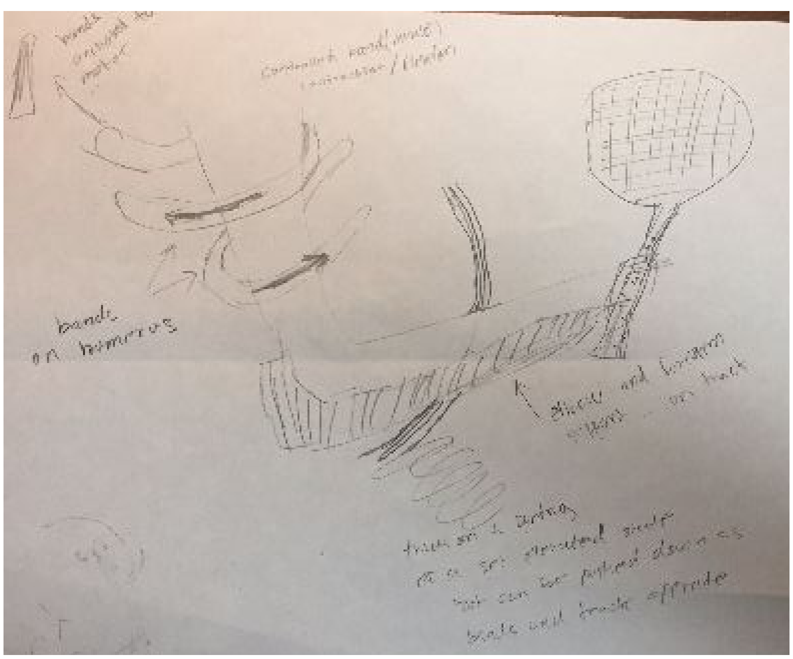
10.2 Background Figures



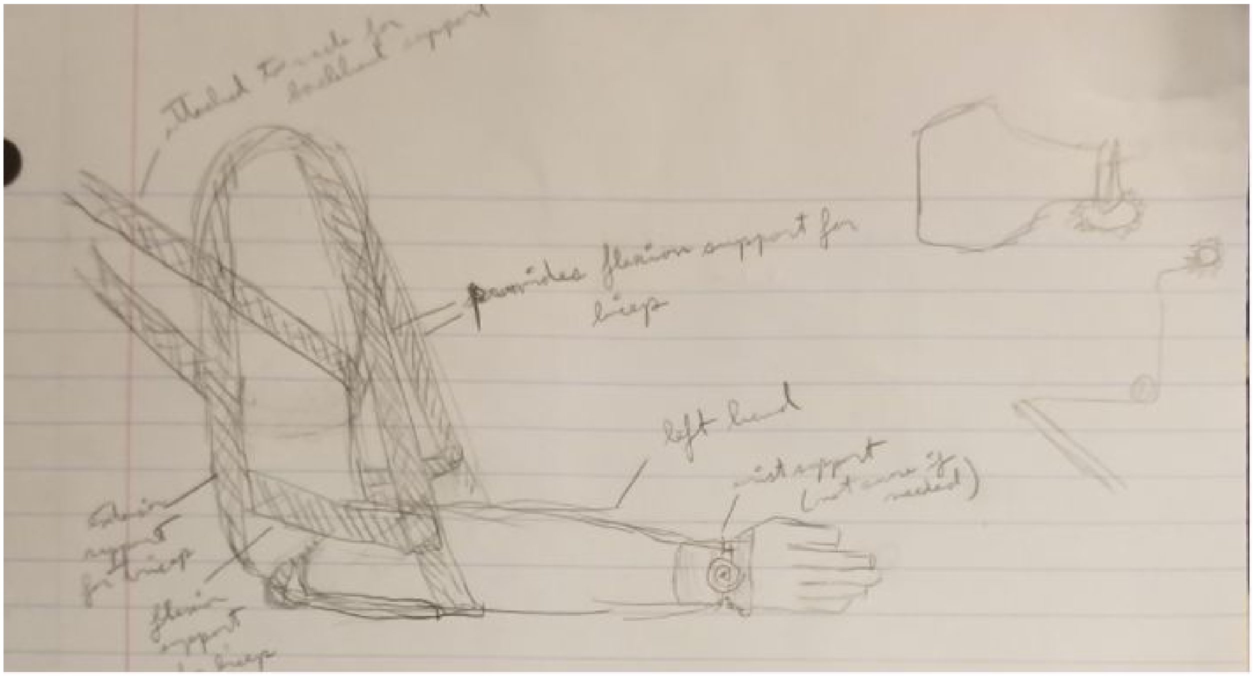
Figure[10.2.1]: Dan conducting a forehand swing; black arrow indicates the direction of the chair movement to account for the loss of lower body force. The red arrow is the incoming motion of the tennis ball.

Figure[10.2.2]: 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.

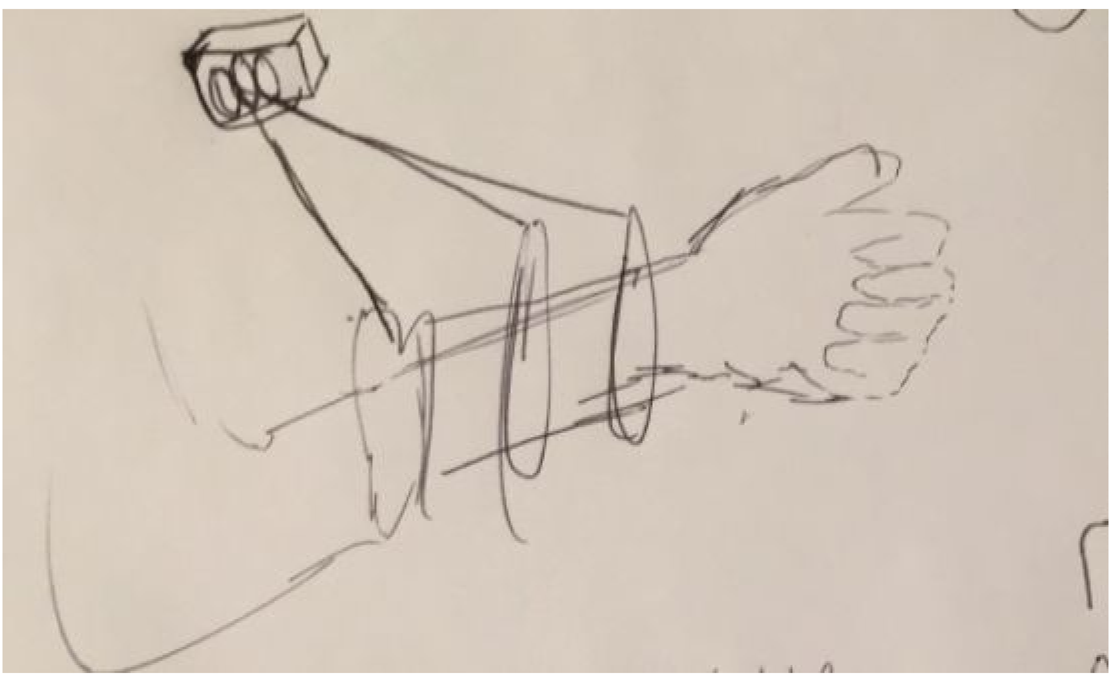
10.3 Preliminary Sketches of Three Evaluated Designs, Track, Band, and Name-tag:



Figure[10.3.1]: Preliminary Sketch of Track Design



Figure[10.3.2] Preliminary Sketch of Band Design



Figure[10.3.3] Preliminary Sketch of Name-tag Design