

Wheelchair Tennis Adaptive Devices for Quad Tennis
Product Design Specifications
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Team:

Zach Alden (leader)

Leslie Franczek (BSAC)

Ben Lahm (BWIG)

Alyssa Walker (communicator)

Will Bacon (BPAG)

Function: The design project client has Becker's Muscular Dystrophy (BMD), which is a slowly progressive muscular disorder caused by a mutation in the dystrophin gene. The client plays in a quadriplegic tennis league, in which the player must have a permanent disability that results in a substantial loss of function in one or both upper extremities. The players are allowed assistive equipment, along with the wheelchair, to facilitate play of the game. The type of equipment varies per individual and their respective conditions, but the client requires an optimized tennis racket grip, tennis ball serving system and an arm support mechanism to aid with raising the racket for a high shot. This equipment must be attached to the client's wheelchair in order to prevent interfering with the game play. The client has requested that we design these wheelchair attachments in order to assist his game play and eventually, that of other individuals in the quadriplegic tennis league. (Ben)

Client Requirements: *The client's specifications are as follows*

- 1: Tennis Racket Grip
- 2: Tennis Ball Launching System
- 3: Arm Support Mechanism

Physical and Operational Characteristics:

1. *Performance Requirements:* (Ben)
 1. The client is looking for an optimized tennis racket grip that helps them maintain a firm grip on the racket without sacrificing wrist mobility or endurance. This grip must be able to withstand typical sports conditions such as sweat, strain and heat without limiting the client's wrist movement, as that is the source of power behind a shot.
 2. As a result of their condition, it is difficult for the client to toss a tennis ball in the air for a serve. The tennis ball launching system must be mounted to the wheelchair and able to launch the ball to an optimal height and location for the client to hit. This optimal height is around 42 inches and location is about 36 inches from the wheelchair.
 3. The arm support mechanism needs to give the client the ability to lift his racket arm in order to hit a high ball or serve. This support mechanism must not limit the client's ability to lean forward or backward in the wheelchair and must be easy to operate quickly in response to a shot.
2. *Safety:* (Zach)

1. The grip device should not injure or irritate Dan during play. This means that the grip should not cut into his wrist or rub his hand raw after continuous movement. The grip should also not cause further limitation to Dan's abilities.
 2. The serving system should not cause injury to Dan's hand, arm, or other parts of the body during the serve. If mounted to the wheelchair, the serving system should not cause the wheelchair to tip. If electrically powered, the system should be noted as such and preventions should be made to prevent accidental electrocution.
 3. The arm support should not injure Dan during play. Cushioning or something similar should be provided with the support to promote comfort and prevent blunt injury or sores on the arm. The device should provide adequate bracing to keep the arm supported, but not so constrictive as to limit function within the arm.
3. *Accuracy and Reliability:* (Leslie)
1. The tennis racket grip should be able to withstand the forces received during a normal session of tennis without altering in any way. A tennis match can last up to 3 hours and the weather may vary from cold and rainy to extreme heat. The grip should not deform for any reason or cause discomfort to Dan.
 2. The service device needs to be able to maintain a constant height and direction throughout duration of play. The height of the device needs to be at knee level for Dan which is 42 inches off the ground. It also needs to be 36 inches away from the wheelchair so Dan has room to swing. These distances should be consistent every time the ball is served. The serving device should also be reliable in weather conditions such as wind that may alter the path of the ball.
 3. The arm support should be able to allow motion in every direction. It needs to be reliable in that it supports the arm in the same way throughout its use. This is important because after practicing using the device, each hit should feel the same to the user. The device should not alter or weaken throughout the duration of play.
4. *Life in Service:* (Allie)
- All:* All three components of the design must be able to function at optimum performance for a minimum of three hours of continuous use. However, the design should operate for durations longer than this time requirement to meet Dan's practice needs. Ideally, all three elements of the design should function with minimal maintenance throughout Dan's lifetime.
5. *Shelf Life:* (Will)
- All:* Each of the adaptive devices will be stored in Dan's van or in his house. If left in Dan's van for extended periods of time, the devices could be subjected to extremely hot temperatures in the summer (as high as 160°F due to heat being trapped inside). In the winter, temperatures could drop to as low as -20° to 30°F, so the devices must be able to withstand both the heat and cold. They could also be stored in very humid conditions during the summer, so they should be able to withstand that as well. Additionally, the devices may move around in the back of Dan's van, so they should be able to withstand minor collisions with each other as well as the interior of his van.

- 1) The grip should be made durable, so that it has a functional shelf life of 5-10 years or more.
- 2) The launching system should be made durable, so that it has a functional shelf life of 5-10 years or more.
- 3) The arm support mechanism will likely consist of two parts -- a brace part and an elastic part. The brace part should be made durable, so that it has a functional shelf life of 5-10 years or more. The elastic part will ideally last 5-10 years, but will probably need to be replaced every 3-5 years, as it will lose its elasticity.

6. *Operating Environment:* (Ben)

1. The tennis racket grip will be subject to the heat, sweat and pressure of the client's hand while playing. The average human body temperature is 97.7 to 99.5 degrees Fahrenheit. The average male hand grip strength is 105-113 pounds. Human sweat has acidic characteristics, with a pH range of 4.5 to 7, and is composed of mostly water and salt. The grip must not be significantly affected by these environmental factors.
2. The tennis ball launching system will be attached to the wheelchair, and therefore, subject to the same operating conditions, such as exterior heat. The launch system should not be affected by normal outdoors temperature, ranging from 100 degrees Fahrenheit in the summer to the minimum indoors temperature of 55 degrees mandated by the International Tennis Federation. The launch system should be water resistant to a degree, but not necessarily waterproof since the client would not be playing outdoors in the rain.
3. The arm support mechanism will be attached to the wheelchair, and therefore, subject to the same operating conditions, such as exterior heat. The arm support should not be affected by normal outdoors temperature, ranging from 100 degrees Fahrenheit in the summer to the minimum indoors temperature of 55 degrees mandated by the International Tennis Federation. The arm support should be water resistant to a degree, but not necessarily waterproof since the client would not be playing outdoors in the rain.

7. *Ergonomics:* (Zach)

1. The grip should accommodate the natural position of Dan's hand during serving and play. The grip should not limit wrist range of motion or inhibit regular tennis serving motions. The grip should provide adequate support to Dan's hand to prevent slipping during the tennis serving motion.
2. The serving system should be easily prepared with minimal input from Dan. The system should be automated to serve the ball to a height of 42 inches from the ground and a distance of 36 inches from the wheelchair without a great extent of force on Dan's part. The height of the serve would be ideally adjustable within a range of around 6 inches to account for fluctuations in Dan's serving motion.
3. The arm support should serve to support arm movement and not impede it. The support will be required primarily against gravity, but the design should not prevent downward motion of the arm as well. The support should improve ROM by 10%.

8. *Size:* (Leslie)

1. The grip needs to be able to fit on the handle of a racket so that the overall grip size is between $4\frac{1}{4}$ to $4\frac{5}{8}$ cm. Dan has played with a variety of grip sizes and does not have a preference of one over the other.
2. The serving device should be around 10cm in diameter. It will need to be able to fit a tennis ball (67mm) but it should be as compact as possible so as not to get in the way while playing. The device may also have a component to activate the serve which would need to be the appropriate size for Dan's foot or right hand to reach it comfortably.
3. The arm support needs to be able to fit comfortably around Dan's arm. Its length will depend on the chosen design but would ideally support both the upper arm as well as the forearm. The rest of the device should be long enough so Dan can reach across his entire body while still being supported by the device: about 4 feet. Although the device should be compact so that it does not have any extra parts to get in the way, it is more important that it can reach to Dan's full range of motion.

9. *Weight:* (Allie)

1. The racket grip should be relatively lightweight so that it does not restrict Dan's range of motion or serving movement.
2. Although the allowable weight of the serving system is more flexible than the maximum weight for the other design components, it should not impede Dan's ability to move effectively. Furthermore, it is critical that the serving system does not cause the wheelchair to become unbalanced. In order to account for this, we will most likely use a counterweight.
3. The arm support device should be relatively lightweight so that it does not limit Dan's range of motion or serving movements. Ideally, the weight of the arm support device will be accounted for through the use of resistance bands, which eliminate the force of gravity on Dan's arm.

10. *Materials:* (Will)

1. The tennis grip should be made of a lightweight material that will not infringe upon Dan's ability to move his wrist or fingers. It should also have some resistance to heat and cold such that it doesn't burn Dan's hand in hot temperatures or freeze it in cooler temperatures. Possible materials for the grip include rubber or silicon.
2. The serving system will be made of a lightweight or medium weight material that can withstand a moderate amount of internal pressure (necessary to launch the ball). It too should have some kind of resistance to transmitting heat so that Dan doesn't accidentally burn himself by touching it on a hot day. Possible materials for the serving system include PVC pipe, an air compressor, a spring,
3. The arm support mechanism should be made of lightweight materials. Some of the materials will act as a brace to support Dan's arm and those should be made of flexible, sturdy material. Other materials will serve to actually make it easier for Dan to move/raise his arm and those should have some kind of elastic property. Possible materials for the brace include neoprene, velcro (straps), nylon, or

polyester. Possible materials for the elastic portion include resistance bands, rubber bands, or springs.

11. *Aesthetics, Appearance, and Finish:* (Will)

All: A rule the USTA has in the quadriplegic tennis league limits the number of exposed logos a player may have on their person/wheelchair. As a result of this, all devices shall be devoid of logos, so as not to infringe on this rule.

1. The grip should have a smooth finish, so that it doesn't irritate or bother Dan's wrist/hand in any way. The color of the grip will most likely be black to match the grip color on Dan's racquet. The shape of the grip will be molded to fit with the shape of Dan's hand/fingers.
2. The service launching system will have a fairly smooth exterior texture and will be cylindrical in shape. The color of the serving system could be a variety of hues, but black seems most likely as it would blend in with the wheelchair.
3. The arm support will also be smooth to prevent any abrasion between it and Dan's arm. The arm support will fit closely to Dan's arm and won't be bulky. The color of the arm support will be chosen based on Dan's preferences, but black once again seems the likely choice.

12. *Product Characteristics:* (Zach)

1. **Quantity:**

- i. As of now, only one of each device tailored for the client is necessary, with a possibility of expanding the use of this device to multiple users. A future application would be expanding the range of device measurements to accommodate a larger audience and modifying the designs for faster production to reach this larger audience.

2. **Target Product Cost:**

- i. Total target product cost is \$500, but this amount is flexible.
 1. The upper target cost for the grip is \$50-100.
 2. The upper target cost for the serving system is \$200-250.
 3. The upper target cost for the arm support is \$200-250.

13. *Miscellaneous:* (Leslie)

1. **Standard and Specification:** The designed devices must meet USTA standards for play. Dan specified that some devices may not have been thought of yet so they may make a new regulation if the new equipment is brand new to the adaptive community.
2. **Patient-Related Concerns:** Dan is most concerned with the devices aiding his tennis abilities. During hot weather he gets very overheated so none of the devices can add to his body temperature. They should not constrict sweat in any way. He is also concerned about his movements being limited by the devices. The arm support can not take away any degree of freedom of his movement and the grip cannot take away his wrist movement.
3. **Competition:**
 - i. The most common method of grip in quadriplegic tennis right now is using medical tape to secure the player's hand to the racket. Using tape limits the movement of the wrist which essential to Dan's style of play. It also

makes the hand sticky and becomes uncomfortable in high temperatures. There are also other less common methods including rubber bands.

- ii. Currently, the most common method for adaptive serving helps to have assistant toss the ball for the player. This method requires practice with the assistant and can be inconsistent. There are also serving machines that are used for practice but these tend to send the ball in an arc from its position at the net rather than just up in the air.
- iii. The arm support currently has many devices on the market, but they are all expensive and many do not fit Dan's needs. Some of them are meant just for children while others take away some degree of freedom of movement. The X-Ar is a device on the market now that was created to aid workers with jobs that required repetitive movements. It essentially takes away the force of gravity acting on the arm. It works using spring and looks very similar to a product we might want to create.

4. **Customer:** Dan Dorszynski, Private Client