# Climber's Forearm Trainer

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## Abstract

"Climber's Elbow" is a condition affecting many rock climbers. It is caused by overuse and imbalances of the muscles in the forearm, leading to microtears of the tendon connecting to the medial epicondyle of the humerus. The common climbing position, hands pronated and elbows bent, puts a lot of stress on the flexor muscles and not as much on the extensors. A device was needed to strengthen the flexors and extensors of the forearm, with emphasis on the pronator teres. By strengthening the pronator teres and other forearm muscles, the goal is to prevent the development of, or aid in the rehabilitation from, "Climber's Elbow". The final design, The C.F.T., includes a 3D printed L-shaped piece that is secured to the forearm and biceps by velcro straps to support the elbow. It also includes a handle, used for flexion, extension, pronation and supination of the wrist, that is connected to a resistance band which loops across the back of the L-piece. Tension testing was done on the resistance bands, which showed that elongating the band increased the amount of force exerted by the specific band. Additional testing showed that The C.F.T. activated the flexor and extensor muscles, suggesting it is a reliable way to strengthen the forearm. Looking to the future, more testing could be conducted to better understand the activation of muscles while using the device. More research could also be done on small adjustments that could increase the safety and effectiveness of the device.

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# I. Introduction

## 1. Background

Medial epicondylitis, which is more commonly known as "Climber's Elbow," is a condition that affects many rock climbers and can prevent them from being able to climb for up to six months [1]. Rock climbing is a very forearm intensive sport, constantly activating the four flexor muscles located on the inside of the forearm. These muscles, as seen in Figure 1, are involved with the movement of the wrist and elbow [2]. All four of these muscles share a common tendon that connects to the medial epicondyle, located on the interior of the humerus [2]. Among these muscles is the pronator teres, highlighted in yellow in Figure 1. The pronator teres is involved with both the flexion of the elbow, as well as the pronation of the hand. When people rock climb, they often find themselves in this position, with their elbows bent and their hands prone, indicating that the pronator teres is being flexed.

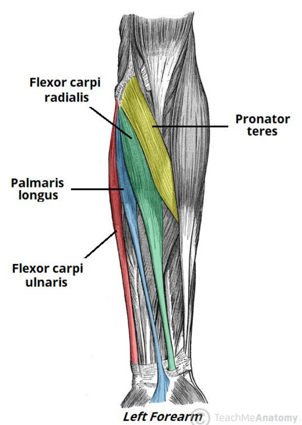


*Figure 1:* This schematic shows the four flexors of the forearm, each in a different color. The pronator teres is highlighted in yellow [3].

The constant use of the flexors, in the grip-heavy sport of rock climbing, can lead to strain on the tendon that connects the flexors to the medial epicondyle. When there is too much strain on this tendon, microtears can develop, in which the normally organized collagen of the tendon becomes disoriented and fiber separation occurs as well [4]. This causes pain in the elbow and is what characterizes medial epicondylitis [5]. This problem typically develops through the overuse of the flexors without giving the body enough time to recover between uses [5]. Another contributing factor to medial epicondylitis is the imbalance in strength between the flexors and extensors of the forearm, with a larger imbalance contributing even more to the condition [6]. Methods to help rehabilitate after this injury, as well as prevent it, include stretching the muscles involved, resting for longer periods of time, massaging the affected area, and performing eccentric exercises to strengthen the muscles involved [3,5].

There are currently no devices on the market that are able to target both flexors and extensors of the wrist while also providing resisted pronation and supination. A common device found in many gyms is the hangboard, as seen in Figure 2, which solely engages the flexors. Climbers use this by hanging by their fingers from holes of varying depths. The "Gripmaster Hand Strengthener," as seen in Figure 3, and other similar devices incorporate spring resisted "buttons" or rubber rings to resist the flexion of the fingers. However, they do not engage the extensors or allow for the resisted rotation of the wrist [7]. Some designs have resistance bands that the user puts their fingers inside of and extends out against, engaging the often overlooked extensors. The "Metolius GripSaver Plus," seen in Figure 4, uses this design in conjunction with a squeezable ball to allow for the flexors to be engaged in addition to the extensors [8]. The "Metolius GripSaver Plus" does not, however, provide resistance while pronating and supinating the hand. All of these current devices are able to work parts of the forearm but do not provide a full range of resisted motion in one product.

*Figure 2:* A rock climber hanging from a hangboard [9].


*Figure 3:* The Gripmaster Hand Strengthener [7].


*Figure 4:* Metolius GripSaver Plus [8].

## 2. Problem Statement

A device was needed that can strengthen the flexors and extensors of the forearm while also providing resisted pronation and supination of the hand. This device must better prevent "Climber's Elbow" and assist in the rehabilitation process from this injury via the strengthening of the forearm muscles. The device will include adjustable resistances that will allow the user to increase the amount of force as the muscles grow stronger. An adjustable resistance will allow the device to be used for other athletes, not just climbers. The forearm trainer should be able to strengthen as many of the forearm muscles as possible. The device also needs to be portable, so that it can be used in a variety of environments.

## 3. Design Research

Each individual has different sized forearms varying in length and in width. A device must be created that is adaptable for these different sizes. As of March of 2019, 50% of male heights fall within the range of 5'7" and 5'11", whereas 50% of female heights fall between the range of 5'2" and 5'6" [10]. Anthropometric tables are used to determine the forearm and upper arm segment lengths based on the average lengths for the specified heights. Since the shortest height is 5'2" (62 inches) and the tallest height is 5'11" (71 inches), the proposed device should incorporate these sizes and everything in between.

Length for the forearm:

$$\text{Length} = 0.146H$$
$$\text{Length} = 0.146 * 71 = 10.366''$$
$$\text{Length} = 0.146 * 62 = 9.052''$$

Length for the upper arm:

$$\text{Length} = 0.186H$$
$$\text{Length} = 0.186 * 71 = 13.206''$$
$$\text{Length} = 0.186 * 62 = 11.532''$$

Knowing that the ranges of the forearm are roughly between 9.052'' and 10.366'' and that the upper arm is between 11.532'' and 13.206'', an effective device was designed to fit a variety of users without causing any pain or discomfort.

The device was intended for climber's with, or those prone to developing, "Climber's Elbow." Grip is an important factor in climbing and therefore is important to incorporate into a design. Grip force was found to be significantly larger when the wrist is fully extended than when it is held at an angle. An increase in grip aperture (distance between the thumb and the fingers) will also increase the grip force [11]. Incorporating different grip sizes could help strengthen all the muscles involved in gripping.

## 4. Design Specifications

To obtain a design that fits the clients needs, the focus was to ensure that the device would be adaptable to a variety of people. This would include varying weights or resistance, as well as the ability to accommodate different sized forearms. The device also needed to be able to withstand the force generated by the weights and the users for extended periods of time. In addition, the client wanted the device to be able to be used by an everyday consumer in a variety of different locations (gym, home, etc.). To achieve this, the device needed to be portable and have the ability to be quickly assembled for easy use. A complete list of the product design specifications can be found in Appendix A.

### 5. Client Information

Dr. Chris Vandivort completed his residency in Emergency Medicine at the University of Wisconsin Madison and currently works at the UW Hospital. Dr. Vandivort is an avid climber who developed "Climber's Elbow" from climbing in the gym.

## II. Preliminary Designs

### 1. The Hydraulic Arm Press

The Hydraulic Arm Press (Figure 5) would allow for flexion and extension of both the wrist and elbow as well as pronation and supination of the forearm. The Hydraulic Arm Press would lie on a table top and be secured in place by industrial strength suction cups. The device would work by resting the forearm on the top plate and then strapping the forearm in. The straps would ensure that the user would not have any lateral movement that could cause muscles to be activated in an unwanted way. The edge of the device would have a locking hinge mechanism that could be unlocked for flexion and extension of the elbow. This motion would be performed by placing a hand on the ball and simply pulling the plate and the ball upward. The hydraulic system attached to the ball would provide the resistance during the motion. The locking hinge at the edge of the device could be locked, and the joint between the ball and the arm plate could be unlocked to allow for flexion and extension of the wrist. This motion would occur by gripping the ball and moving the wrist up and down. Ball and socket hinges would allow for the hydraulic system to not only move up and down but to also rotate if the ball were to rotate. This would allow for pronation and supination of the forearm.

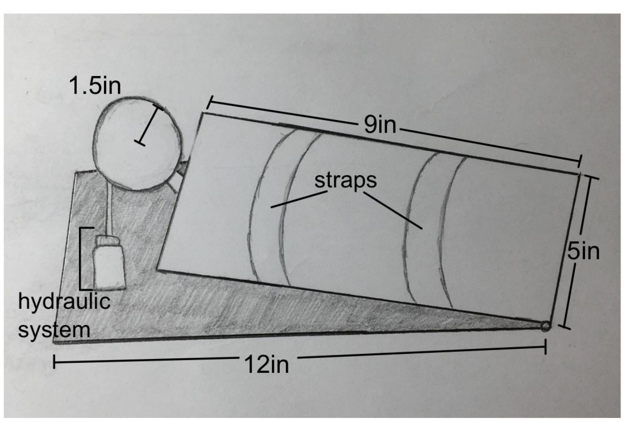

*Figure 5:* The Hydraulic Arm Press idea. It involved a hydraulic system that will vary in resistance.

## 2. The Resistance Cube

The Resistance Cube (Figure 6) would allow for extension and flexion of the wrist as well as supination and pronation of the forearm. The Resistance Cube would lay on a flat surface and be held in place with suction cups, along with additional support provided by the user's free arm. The user would insert their hand into the cube and grab the handle. The handle would be connected to resistance bands originating from each of the eight corners of the cube. Bands of varying resistance would be stored within the outer frame of the cube and would allow the user to increase or decrease the resistance of the exercise to their preference. The resistance bands would be attached to the handle and corners of the cube by miniature carabiner clips. While gripping the handle, the user could move their wrist in controlled upward and downward motions to exercise the extensor and flexor muscles. The user could also rotate the handle to the left and right, allowing for pronation and supination of the forearm.

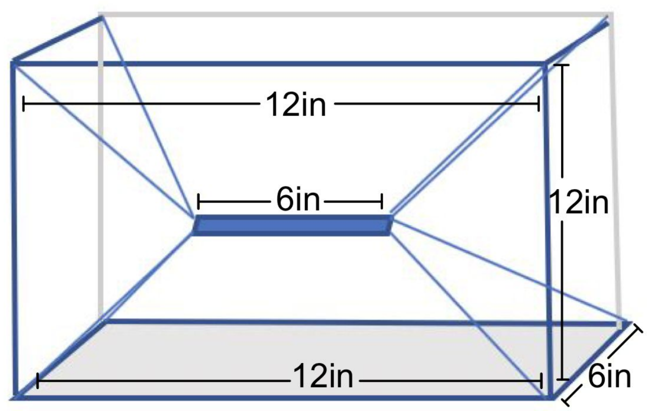


*Figure 6:* The Resistance Cube idea. It involved eight resistance bands that are interchangeable for varying weights.

## 3. The Resistance Ring

The Resistance Ring (Figure 7) comprised an outer frame that would house resistance cables attached to the vertical handle in the center of the device. The center ring and handle would be on tracks along the top and bottom of the frame, allowing for the center ring and handle to slide horizontally, or vertically if the frame were rotated 90 degrees. The bands within the frame would create resistance against this sliding, allowing for the resisted extension or flexion of the wrist. The holes in the center of the handle would allow the user to place their fingers inside and build their finger strength by moving the ring horizontally or vertically, solely with their fingers. In addition to this, the ring framework would also house resistance bands.

These bands would connect from the top and bottom of the handle to the framework in the middle of each hemisphere of the ring. These four bands would allow the user to also hold the handle and pronate and supinate their wrist, while receiving resistance from the bands within the ring framework. The Resistance Ring would best be used sitting on a flat surface, to avoid unwanted rotation of the framework when in use. This device would allow for the strengthening of forearm flexors and extensors, while also providing resisted pronation and supination.

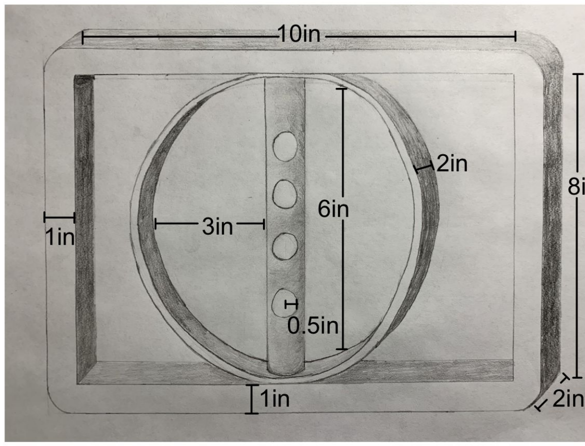


*Figure 7:* The Resistance Ring idea. The frame included resistance bands that could be interchanged for different resistances.

## III. Preliminary Design Evaluation

### 1. Design Matrix

| Design Criteria | Weights | | Hydraulic Arm Press | | Resistance Cube | | Resistance Ring | |
|---|---|---|---|---|---|---|---|---|
| Effectiveness (25) | 4/5 | 20 | 4/5 | 20 | 5/5 | 25 | 5/5 | 25 |
| Ease of Use (15) | 4/5 | 12 | 5/5 | 15 | 4/5 | 12 | 4/5 | 12 |
| Adaptability (15) | 5/5 | 15 | 5/5 | 15 | 5/5 | 15 | 3/5 | 9 |
| Cost (10) | 3/5 | 6 | 3/5 | 6 | 5/5 | 10 | 3/5 | 6 |
| Comfort (10) | 4/5 | 8 | 5/5 | 10 | 4/5 | 8 | 4/5 | 8 |
| Safety (10) | 2/5 | 4 | 5/5 | 10 | 2/5 | 4 | 3/5 | 6 |
| Portability (5) | 3/5 | 3 | 4/5 | 4 | 4/5 | 4 | 4/5 | 4 |
| Durability (5) | 5/5 | 5 | 4/5 | 4 | 3/5 | 3 | 4/5 | 4 |
| Ease of Fabrication (5) | 5/5 | 5 | 4/5 | 4 | 5/5 | 5 | 2/5 | 2 |
| Total (100) | 78 | | 88 | | 86 | | 76 | |

*Figure 8:* The climber's forearm trainer design matrix. Dumbbell assessment was included to use as a comparison with the three preliminary designs.

## 2. Justification of Criteria

*Effectiveness:* The effectiveness of the product was determined by how well the device would strengthen the forearm muscles, as well as its ability to change levels of resistance. This was weighted the highest (25%) due to the fact that the main purpose of the product was to strengthen forearm muscles in order to avoid climber's elbow or rehabilitate affected muscle groups after the onset of the injury. Due to their ability to allow for full ranges of motion in multiple directions, as well as their ability to change loading amounts, the "Resistance Cube" and the "Resistance Ring" designs both scored the highest for this criteria. These designs would allow for pronation, supination, flexion, and extension of the forearm, and they would include replaceable resistance bands (Resistance Cube) or cables (Resistance Ring), allowing for increased or decreased loads to best fit the user's needs and abilities.

*Ease of Use:* The ease of use of the product was determined based on the steps a user would have to take in order to properly understand how to utilize the product. This included the steps needed to set up the product and to adjust the resistance as time goes on. "The Hydraulic Arm Press" design scored highest in this category based on the fact that it would require no set-up, and its resistance would be very easy to change. Unlike the other two designs, all that would need to be done to alter the resistance would be the turning of a dial, making it both easy to use and easy to adjust.

*Adaptability:* The adaptability of the product was determined by how adjustable it would be to varying types of people. Each user would be different in size and strength, so a device that allowed these mechanisms to change would be important in allowing everyone to receive the maximum benefit of the workout, making the product more marketable to a consumer even outside of climbing. "The Hydraulic Arm Press," and "Resistance Cube" designs scored equally for this criteria. This was because they each would allow for a variety of changeable weights to fit the strengths of different people and for progression of strength in any single individual. These designs also consisted of adjustable straps to fit various sizes of forearms.

*Cost:* The cost of the product was determined by the price of the individual components of each design and the total cost of production. A lower price would be ideal since it would help make the product more marketable to everyday consumers. The "Resistance Cube" design scored highest in this category and was estimated to have the lowest cost since the elastic bands it required would be cheaper to purchase than the hydraulic mechanism in the "Hydraulic Arm

Press” design and the cables in the “Resistance Ring” design. This design was also estimated to cost the least to fabricate because of its simplicity compared to the other designs.

*Comfort:* The comfort of the product was determined based on how comfortable the user would be while working with it. This was important because any discomfort would decrease the amount of force the user would be willing to apply. Due to the padded arm rest on the “Hydraulic Arm Press” design and the fact that resistance could be released at any point without the repercussions of the snapping of cables or bands, the “Hydraulic Arm Press” scored the best in this category.

*Safety:* If customers would feel unsafe or would be putting themselves in danger when using this product, they would not want to use it. The purpose of this device was to help strengthen and prevent injury, rather than cause injury. Due to the possibility for resistance bands or cables to snap while in use, both the “Resistance Ring” as well as the “Resistance Cube” did not score as well as the “Hydraulic Arm Press.” Additionally, traditional weights pose the risk of being dropped on fingers or toes, decreasing their safety. The “Hydraulic Arm Press” would avoid all of these problems by implementing resistance through a hydraulic system.

*Portability:* A smaller device that would be easier to store would be more appealing to a large variety of customers. The goal of the device was to allow climbers to workout either at home or in a climbing gym, with the device able to be easily transported between different locations. Portability would help set this device apart from existing devices at the gym as well as simple weights that are easily accessible at a gym. The client also requested that the device be portable. This was one of the lowest weighted criteria (5%) because it was not directly related to the performance of the device or the safety of the user. All three of the devices tied as they would all be fairly light and easy to move. The only reason they did not receive scores of five was due to the fact that a table would be needed to set each device on in order to use it .

*Durability:* The durability of the design was determined by the life of force-generating mechanisms of the designs. It was assumed that the frames utilized by these designs would have a relatively long life in service, but the mechanisms used to produce the force would be less durable. While durability was extremely important, it was assumed that all of the devices considered would have a certain standard of durability that would need to be met. Because of this, durability received a lower weighting (5%) compared to other criteria. When all three preliminary designs were compared to simply using dumbbells, none of them were deemed to be as durable. However, both the “Hydraulic Arm Press” and the “Resistance Ring” were equally rated as the force-generating components in them would not be likely to fail with extended use. The resistance bands in the “Resistance Cube,” however, could be likely to snap unpredictably and could need more replacement and maintenance.

*Ease of Fabrication:* The ease of fabrication was based on the perceived fabrication abilities of the team and the ability to use the machines in the TEAMLAB to produce the desired product. The ability of the team to produce a working prototype was important to determine the effectiveness of the design and demonstrate the effectiveness to the client and faculty. If a design was beyond the fabrication abilities of the team, errors in production may lead to flaws in the prototype that would prevent it from performing well. This received the lowest weight (5%) because it was not directly related to functionality or the experience of the user. Out of the three preliminary designs, the "Resistance Cube" design would be the easiest to fabricate as the frame and the handle would be the only parts needing fabrication. The resistance bands would be removable to offer different magnitudes of resistance and would simply be clipped onto the device. The other two designs included more complicated force-generating components to incorporate, but the only one that would be challenging to fabricate would be the "Resistance Ring" as it would incorporate parts that would need incredibly precise fabrication in order to fit together.

## 3. Proposed Final Design

The proposed final design, named the Lock n' Load as seen in Figure 9, was very different than any of the preliminary designs. It had several features that would allow the device to be adaptable to different users while also being completely portable, which was one of the client's main requests. It featured two side supports in opposite-hand configurations with each other that would be placed on either side of the user's arm and attached with elastic straps and velcro. Each side consisted of two rectangular plates with two sets of threaded holes that would allow for the fixture of curved pieces around the arm. These arm pieces had slots on either side that would allow elastic and velcro pieces to be looped through to secure the two sides together. The rectangular plates were attached to each other with a screw, which would allow for the configuration of the arm to change when the device was not locked. A locking mechanism was attached at this same location that locked the arm in different positions. This was to meet the client's request for the elbow to be locked in order to isolate the forearm muscles. The top rectangular plates would have two semi-circular loops attached to them that would allow resistance band clips to be fastened to the device. Finally, a handle with two semi-circular loops attached to it would be held by the user with the resistance straps from the top of the device clipping onto the hoops. The incorporation of resistance bands connected to a handle developed from the Resistance Cube idea. This handle would be 3-D printed which would allow for differing rock-climbing grips to be incorporated into the handle and exchanged easily by the user. Resistance bands could be interchanged quickly through the easy access hooks on the device, and this would allow the user to change the resistance of the device easily. The velcro and elastic bands would allow the device to fit on forearms of differing sizes. As it is necessary for the device to be comfortable for the user, foam padding would be attached to the parts of the device that have contact with the user's arm.

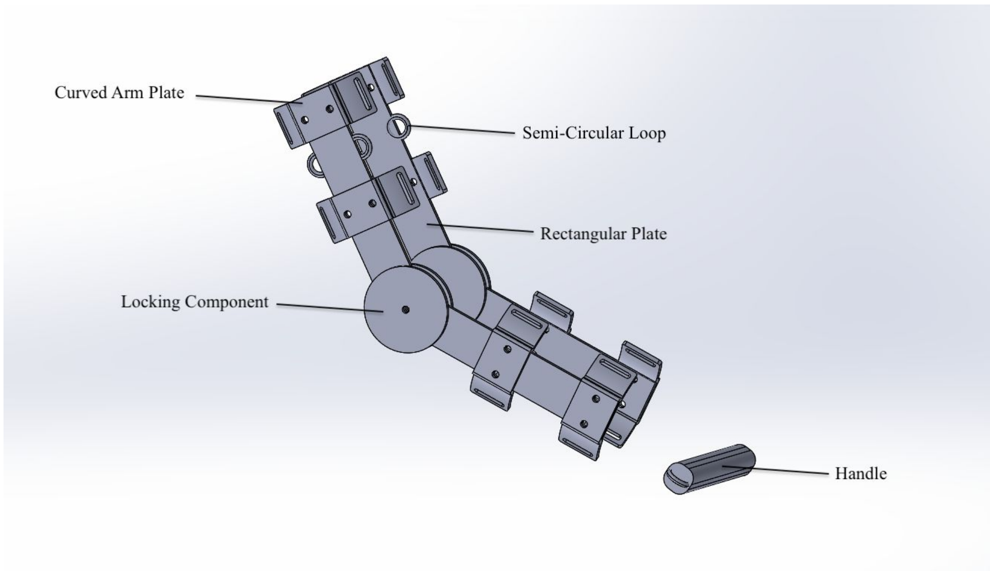


*Figure 9:* The Lock n' Load was the proposed final design. The resistance bands used would attach to the half circle hooks in the brace and the handle, and elastic straps would loop through the slots in the curved arm components and be secured with velcro.

## IV. Fabrication

### 1. Final Prototype

The final design chosen was The C.F.T. (Climber's Forearm Trainer), as seen in Figure 10, consists of three main parts: the L-piece, the handle, and the resistive component. The L-piece, like its name suggests, was in the shape of an L and attached to the back of the arm through velcro straps across the upper arm and forearm. In order to target the forearm muscles, the device needed to prevent the user from employing their upper arm muscles. The L-piece and the straps worked to prevent flexion and extension at the elbow, limiting the use of the upper arm. A resistance band was used to provide varying resistance to any exercise performed. This band was tied through a hollow, cylindrical handle and then attached to the back of the device through a series of hooks, as seen in Figure 11.

*Figure 10*: The C.F.T.

*Figure 11*: Placement of the resistance band around the hooks on the back of the L-piece.

To operate the device, the user simply would select the band to be used, which would already be attached to a handle. This band would then be laid over the top row of hooks on the back of the L-piece and pulled down in between the two hooks. That loop can then be placed around one of the downward hooks on the back, allowing the user to alter the resistance of the band without changing to a new band. Figure 10 and Figure 11 show one possible configuration of the resistance band on the L-piece. Once the band is in place, the user can then strap themselves in and perform the exercises referenced in Appendix B.

### 2. Materials

The C.F.T. was fabricated using upholstery visco memory foam to make the L-piece more comfortable and 18x2'' and 18x1'' cinch straps with eyelets (velcro straps) to secure the device to the user's forearm and biceps. Knurled threaded brass inserts and M4x8mm screws were used to attach the velcro straps to the L-piece. The L-piece and handle were 3D printed with PLA because it was the most dense and sturdy material available. AZURELIFE resistance bands were used to provide variable resistances. A full parts list can be found in Appendix C.

### 3. Fabrication Process

To start, SolidWorks drawings for the L-piece and the handle were created and used to 3D print those pieces. Detailed dimensions of these parts can be found in Appendix D. Knurled threaded brass inserts were placed in the L-piece using soldering techniques, and screws were then used to attach the velcro straps. The velcro straps were cut between the eyelet and the loop. The loop was screwed into one side of the L-piece while the eyelet piece was screwed to the other side of the L-piece. Then, the band length was measured by looping the band around the back of the arm to measure the length at which the bands should be tied. Lastly, the resistance band was threaded through the hollow part of the handle and tied two to three inches shorter than the measured length.

## V. Testing

### 1. Tension Testing

Tension testing of the resistance bands was done to determine how much the force varies between percent elongation and how the force would change from one band to the next. Testing ensured that as the band increased in elongation more force would be applied to the forearm and that the force would have a greater increase when the band was changed from green (light) to blue (medium) to black (high).

Tension testing was done using an MTS Sintech machine. Three different resistance bands were tested; each of them were brand new so that any pre-stretching would not affect the results [12]. Three resistance bands were cut into strips that were 7.62 cm long (half of the width of the band) and 2 cm in width. The sample pieces were then loaded into the grips of the machine and a slight preload was added. The gauge length of each sample was recorded, as this was important for calculating the percent elongation. When fracture of the band occurred, the test ceased. Data was collected for three samples of each colored band. Tests that ended prematurely due to the sample slipping from the grips were not included in the final calculations and were not included in the three samples.

## 2. EMG Testing

Electromyography (EMG) was performed to determine whether or not The C.F.T. correctly activated the flexors and extensors of the forearm. To obtain data, sensors were placed on the flexors and extensors of the forearm as well as the biceps. The sensors were placed on the biceps to determine whether or not The C.F.T. would limit biceps activation and if The C.F.T. isolated the forearm muscles. The test was completed using three different team members; each member performed the same exercises with the same resistance band. First, the test was completed using a dumbbell. This allowed for the comparison of activation between the final design and a pre-existing device that activates the target muscles. Each individual protonated and then supinated the wrist, and then extended and flexed the wrist. Next, The C.F.T. was placed on the arm and the test was completed without any resistance applied. The motions of pronation, supination, flexion, and extension were done. Data was obtained without resistance in order to allow for the comparison of the differences in magnitudes of muscle activation between the motions with and without resistance. Ideally, The C.F.T. would have a larger magnitude than the trial without resistance, which would indicate that there was more muscle activation, and therefore, that the muscles would strengthen through the use of the C.F.T. Finally, The C.F.T. was tested on the user with resistance applied. The user began by holding the handle with their palm facing upward. Then they pronated their wrist twice and then extended the wrist twice. The hand was then flipped so that the user's hand was facing downward. From this position the user supinated their wrist twice and then flexed their wrist twice. Each motion was done twice to test the reliability of the device for each individual.

# VI. Results

## 1. Tension Testing

Theoretical values were provided with the resistance bands and are shown in Figure 14. These values were used to evaluate the precision of the tension testing of the samples. The purple band listed in the figure was not tested and values was therefore omitted for evaluation.

| Color | Level | 100%Elongation | 200%Elongation |
|---|---|---|---|
| | X-Heavy | 27.56 LBS | 38.58 LBS |
| | Heavy | 17.64 LBS | 24.25 LBS |
| | Medium | 13.23 LBS | 17.64 LBS |
| | Light | 8.62 LBS | 11.02 LBS |



*Figure 14*: Theoretical values of force produced by resistance bands.

As shown in the table, the black band would induce the most force followed by the blue and green bands. The completed tension testing matched those trends. The percent increases at 100% elongation and 200% elongation were compared to the theoretical values to test for accuracy, rather than the force values at those elongations. The reason for this was that due to the differences in slimness ratios, the values of elongation at a corresponding force would change but the percent change in force should remain the same [13]. The percent increase was calculated using Equation 1. The values used to calculate the percent increase were the mean values at each level of resistance; these values can be seen in Table 1.

$$percent\ increase\ =\ \frac{Lower\ Value - Upper\ Value}{Lower\ Value} * 100 \tag{1}$$

*Table 1*: Mean and standard deviation of a sample size of 3 for each resistance band.

| | Mean at 100% | Standard Deviation at 100% | Mean at 200% | Standard Deviation at 200% |
|---|---|---|---|---|
| Green Band | 8.68 | 1.65 | 15.3 | 5.54 |
| Blue Band | 16.1 | 1.69 | 24.6 | 2.48 |
| Black Band | 25.7 | 0.849 | 39.0 | 2.48 |

Table 1 also provides the standard deviations of the samples at both 100% and 200% elongation. The higher standard deviations at 200% elongation indicate that those values deviate more from than average than the values at 100% elongation.

The percent increase from the green band to blue band at 100% elongation was found to be 85.5% with a theoretical value of 53.5%. The percent increase from the blue to black band was found to be 59.6%, with a theoretical value of 108%. Percent increase from the green band to blue band at 200% elongation was 60.8%, which was similar to the theoretical value of 60.1%. Also, at 200% elongation, the percent increase from blue to black was determined to be 58.5%, which is far less than the theoretical value of 119%. Force for each percent elongation can be seen in Figure 15.

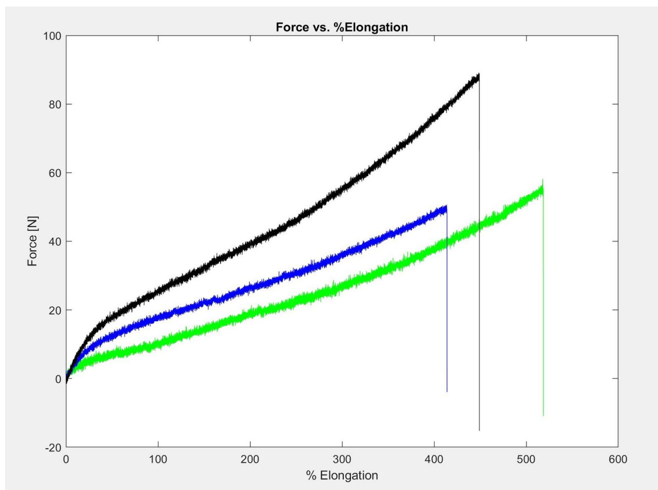


*Figure 15*: Force vs. Elongation of the green, blue, and black resistance bands.

## 2. EMG Testing

Results from the EMG are depicted in Figures 16-18. Flexor activation is shown in green and the extensor activation is shown in red. Accuracy of The C.F.T. was determined by the comparison of the dumbbell muscle activation to the resistance band activation. Reliability of The C.F.T. to strengthen the muscle was found by comparing the no resistance magnitude of activation to the resistance magnitude of activation.

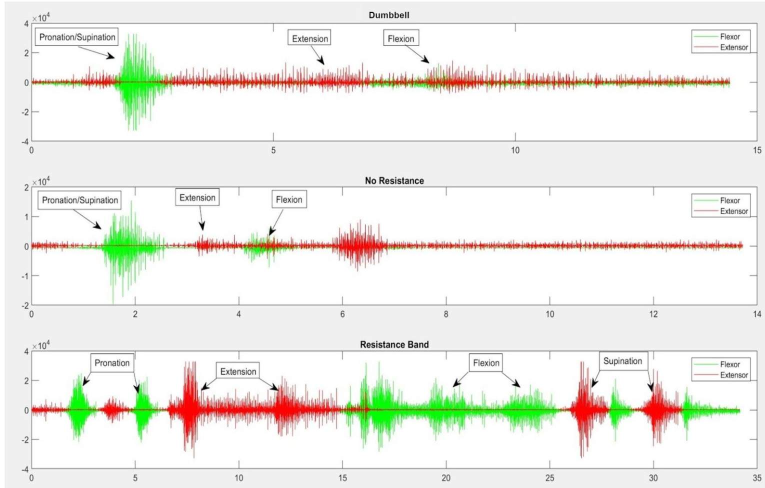


*Figure 16:* EMG of Subject 1.

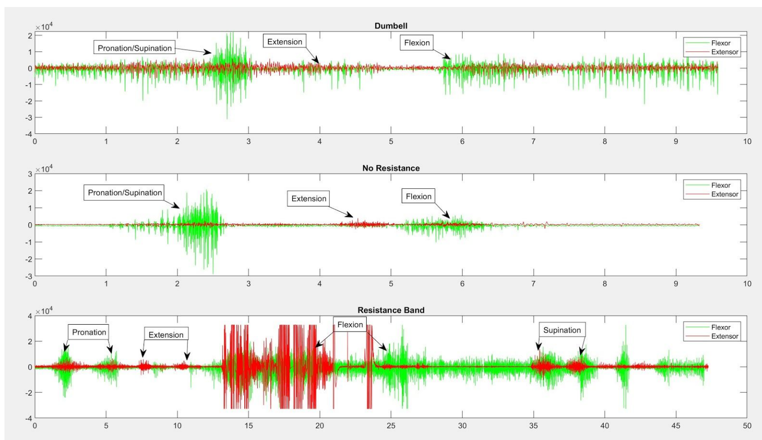


*Figure 17:* EMG of Subject 2.

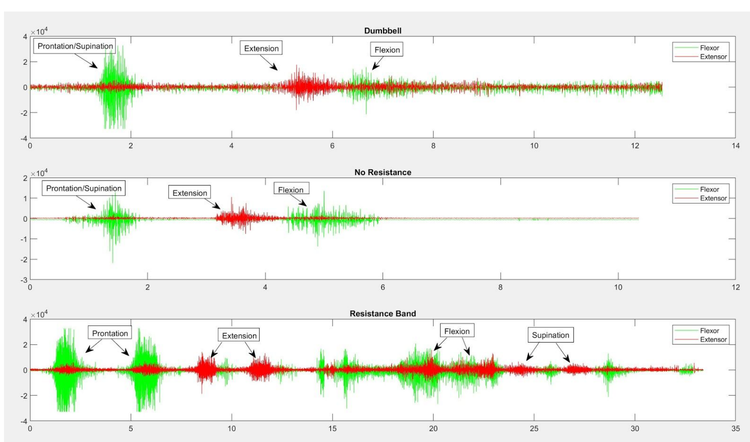


*Figure 18:* EMG of Subject 3.

Figure 16 represents the most accurate activation of both the flexors and the extensors. The flexors were activated during the motions of pronation and supination while the extensors remained inactive. Subject 2, shown in Figure 17, provided inconclusive data for the extensors. The extensors were shown to only activate during a time when the resistance band rubbed along the sensor. In Figure 18, the extensors were not completely inactive, but they were activated at a lesser extent than during extension. The extensors were shown to be activated during supination with the resistance band, but this did not occur during the dumbbell or no resistance trials. While the extensors were activated during extension, the flexors were inactive; this was true for all three cases. Data for the flexors were considered to be accurate and were used to evaluate the effectiveness of The C.F.T.

One goal of the device was to limit the activation of the biceps so that the force provided by the resistance bands would be directed to the forearm muscles. Figure 19 shows the EMG results of the biceps during testing.

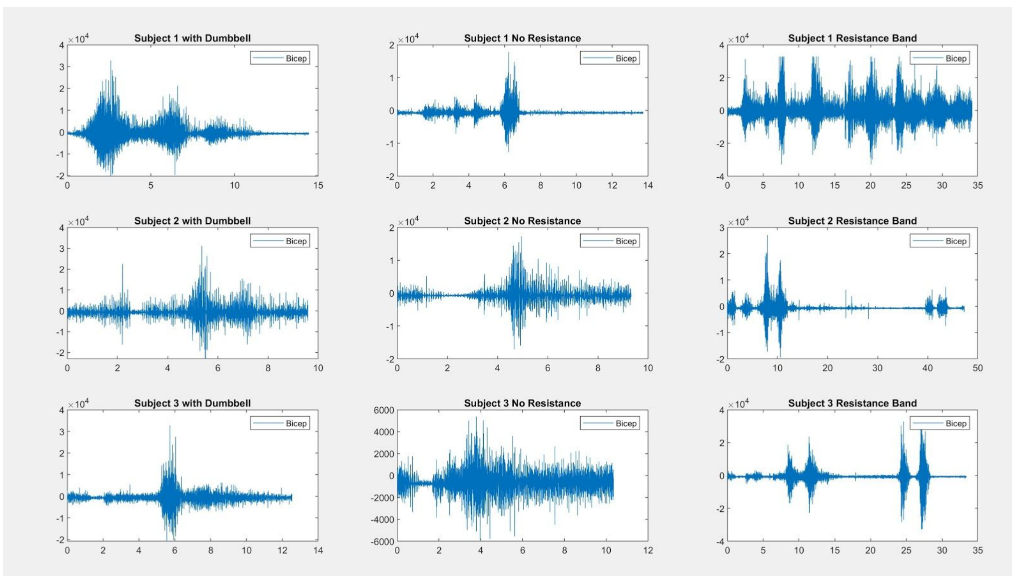


*Figure 19*: EMG of biceps activation across all three subjects under different conditions.

As seen in Figure 19, biceps activation varied between individuals and between the different conditions. Subject 1 had high activation when resistance was provided and little activation with no resistance, while Subject 3 had greater activation with no resistance than with resistance.

## VII. Discussion

When analyzing the tension testing, it was noted that at higher elongations, the standard deviation of force was greater. This means that the reliability of the force exerted by the resistance band was less than the reliability at smaller elongations. In addition, the values of the blue and black resistance bands were vastly different, and therefore, the accuracy of the force values and reliability of the percent increase of force per percent elongation was inconclusive. It was also concluded that increasing the percent elongation of the resistance bands by any small amount would increase the amount of force that the resistance band exerts. This indicated that the user would experience more resistance as the band was stretched out. The hooks incorporated on The C.F.T allow for the resistance to change by hooking the band on a different hook, and this data supports their effectiveness. It was also concluded that by changing the resistance band, the amount of force applied per percent elongation would be higher for the resistance bands of higher advertised resistance rating than the resistance bands of lower resistance ratings. This indicates that changing out the resistance bands will allow the user to increase or decrease the amount of resistance they receive, allowing them to modify the resistance to their needs with different resistance bands.

From the EMG results, it was concluded that The C.F.T. accurately activated the extensors and flexors of the forearm. This was determined based on the activation peaks seen in Figures 16-18. When the subjects pronated, extended, flexed, and supinated their wrists while using The C.F.T, there are clear peaks in the data. This indicates that the muscles that were targeted by the device were firing as expected. In addition, the height of the spikes (magnitude of activation) in the figures increased with elevated resistance. The change in magnitude did differ between subjects, however this was likely due to the difference in tension of the resistance band between subjects due to varying arm lengths as the length of the band itself was the same for every subject. Although the amount of change varied, it was still concluded that the inclusion of resistance would increase muscle activation in order to strengthen the forearm muscles. However, the EMG results for the biceps were inconclusive. Due to the large variation in results between subjects, it cannot be concluded whether or not The C.F.T. isolates the forearm muscles and limits activation of the biceps.

Sources of error during tension testing could have occurred from a variety of different things. For example, the gauge length testing was smaller than the length of the band. A smaller gauge length causes necking to occupy a higher portion of the sample and causes a premature fracture. Also, seen in a few of the sample pieces, a sliver appeared along the side of the band indicating a stress concentration that would cause premature fracture and force production. A stress concentration could have occurred from the cutting of the resistance bands. For future testing, slimness ratio would be taken into consideration to provide more accurate results for the force at a specific elongation. This would allow for a better comparison to the theoretical values that were shown in Figure 14.

Further testing would want to be conducted to determine the percent elongation for which the full length resistance band would fracture. This is important as a safety factor, especially for the thinner bands. A maximum stretch length should be included on the bands so that the user would not experience a failure that could result in injury.

A possible source of error in EMG testing was that the design was altered after completing testing, so the earlier design that was tested on did not accurately represent the final design. The velcro straps were adjusted to be slightly higher on the biceps and memory foam padding was added along the length of the L-piece, both of which could have affected the biceps activation if they had been implemented into the design prior to testing. Also when performing pronation and supination exercises, the resistance bands may have rubbed on the electrodes, causing the data to be skewed.

## VIII. Conclusion

"Climber's Elbow" is a condition that affects many rock climbers and is caused by muscular imbalances between the flexors and extensors leading to microtears and pain. A device is needed to strengthen the forearm muscles, specifically the pronator teres, in order to try to prevent or slow the progression of "Climber's Elbow." The C.F.T. (Climber's Forearm Trainer) was chosen as the final design. The device consists of an L-piece with velcro straps securing the biceps and forearm along with a handle attaching resistance bands to hooks on the back of the L-piece. The user is able to strap themselves into the device and hold the handle to perform flexion, extension, pronation, and supination exercises. By testing the resistance bands and electrical activity in the forearm muscles, the device was concluded to accurately target and strengthen the desired muscles with each exercise. In the future, more testing would be done, specifically EMG testing, to better understand the activation of the biceps within different exercises. EMG testing would also be used to measure the magnitude of muscle activation in the forearm muscles using The C.F.T. in comparison to other competing devices and exercises. Looking ahead, further research would be conducted in order to continue improving the design. Tube resistance bands, especially, would be considered as an alternative to the current resistance bands due to them being less bulky and more aesthetically pleasing. These may be easier to maneuver around the hooks on the back of the L-piece and may attach better to the handle. The design would also be made more comfortable for the user by incorporating softer straps and adjusting the angle of the L-piece. This could be done by adding a locking mechanism to the elbow joint of the L-piece to allow the user to adjust the angle according to their needs. Additionally, variable handles would be created that more closely resemble the different grips that climbers use, such as slopers and crimps. A safety release system, more developed than simply letting go of the handle, would also be desired and integrated into the device.

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## X. Appendix

### Appendix A: PDS

# Climber's Forearm Trainer

Product Design Specifications
Client: Dr. Chris Vandivort
Team: Brittany Glaeser, Kaitlin Lacy, Noah Pollard, Grace Johnson, Gabby Snyder
9/20/19

**Function:**

Many climbers may develop a condition known as "Climber's Elbow" in which the tendons between the pronator teres and forearm muscles to the medial epicondyle of the elbow develop microtears that accumulate over time. Currently, there are stretches available to climbers to help ease the discomfort and delay the onset of this injury. A device is needed to help build muscle strength in the forearm to help prevent this injury or at least slow its progression. The device will include adjustable resistances that will allow the user to increase the amount of force as the muscles grow. An adjustable resistance will also allow the device to be used for other athletes; not just climbers. The forearm trainer should also be able to strengthen as many of the forearm muscles as possible. The device also needs to be portable enough so that it can be used in a variety of applications.

**Client Requirements:**

- The device must not cause the client any discomfort as it could affect the amount of force they are willing to exert; therefore, negating the purpose of the device.
- The device should include a component that allows the user to vary the resistance..
- The device should act on a large variety of the forearm muscles.
- The end position should end in an eccentric stretch of the wrist, this will allow the device to not only strengthen but stretch the muslces, preventing muscle strain.
- The setup of the device should be simple enough so that the user will not require any additional help.
- The cost should be kept as minimal as possible without affecting the quality of the design, with small grip strengtheners costing about five dollars and hangboards ranging

in price from $80 to $450. This would allow for a larger profit margin if the device would be used for commercial sale.

- The device should be able to be used freestanding, without any other supporting structures such as a table.

**Design Requirements:**

1. **Physical and Operational Characteristics**

    a. **Performance Requirements:**
        - It will most likely be used daily if used in a home setting. If in a gym setting, multiple uses per day would be expected. Each use would most likely take five to ten minutes.
        - Will likely undergo various changes in weights to fit the strengths of various users.
        - Able to withstand force exerted by the user.
        - Keeps the biceps and upper arm relatively rigid in comparison to the forearm.
        - Targets the flexors and extensors of the forearm, especially the pronator teres.

    b. **Safety:**
        - Must be comfortable enough so that the user can exert force without any pain.
            1. No sharp edges or corners.
            2. No unwanted pressure; may include cushioning.
        - Accommodate climber's with various size forearms; this could be adjustable size or creating devices with varying sizes.
        - Must be strong enough so that the user's force would not alter the device in any way.
        - Must include a safety release system if the user is unable to quickly detach themselves from the resistive components.

    c. **Accuracy and Reliability:**
        - If using weights, they must be accurate to their advertised weight within a one pound margin of error.
        - If resistance bands or cables are used, increasing the elongation or thickness of the resistance bands or cables needs to increase the force that the user is exerting.

- Must consistently and accurately exert force on the forearm muscles equivalent to the weight or resistance added.

d. **Life in Service:**
- Five to ten years for the permanent components of the device.
- If resistance bands or other removable components (such as cushioning or straps) are incorporated, these would need to be changed out periodically.

e. **Shelf Life:**
- Resistance bands used on the device must be good quality so that they would not deteriorate over time.

f. **Operating Environment:**
- The device will most likely be used at home or at a gym.
- The portability of the device could mean that there is a chance of damage when the device is being moved.
- As the device will be used indoors, there will not be any exposure to extreme temperatures or other damaging outdoor conditions. The likelihood of chemical exposure will also be minimal as it will be stored indoors and should only come in contact with products that would not be harmful to the user.
- Damage could arise while attempting to change the weight/resistance of the device.
- Damage could occur as the subject is placing their forearm into the device
    1. The damage could be in potential straps or bands.

g. **Ergonomics:**
- The device needs to be able to incorporate different sized forearms.
- People with different forearm strength will be using the device, so it needs to be accommodating for a range of strengths.
- The device will not incorporate weights above 30 lbs.

h. **Size:**
- Large enough to comfortably fit an average adult forearm. No longer than two and a half feet.
    1. May have adjustable components to fit a larger variety of people.

i. **Weight:**
- Less than 50 pounds, including any detachable weights.

1. Ideally, it will weigh much less than this.

**j. Materials:**

- No material restrictions have been made at this time.
- The device needs to be fairly comfortable to use so some type of padding will need to be incorporated.

**k. Aesthetics, Appearance, and Finish:**

- No unfinished points or sharp edges.
- Should be comparable to a professional product that is appealing to a consumer's eye.
- No excess material should be hanging or protruding from the device.

## 2. Production Characteristics

**a. Quantity:** Only one Forearm Trainer needs to be produced for the time being; only needed as a prototype and testing purposes.

**b. Target Product Cost:** A starting budget of $500 will need to be kept, but keeping the cost as minimal as possible will increase profit margin if it were to be used for consumer sales.

## 3. Miscellaneous

**a. Standards and Specifications:**

- Values stated in SI units are standard.
- Should be stable in storage, unloaded, and in the intrinsically and extrinsically loaded use conditions.
- Should support user and additional loads without breaking.
- All sides and corners should be free of burrs and sharp edges.
- All corners should smooth ("radiused or chamfered").
- Areas where pinching, crushing, "shearing" could occur should be "guarded" or avoided.
    1. If not, need a specific warning label.
- All locking mechanisms shall function securely at all available adjustment positions.
- Knobs and levers shall not interfere with user's range of motion.
- Integral hand-grips- conspicuous and reduce slippage.

- Applied hand-grips- reduce slippage and withstand an applied force of 90N (20.2 lb) with movement in direction of applied force.
- Rotating hand-grips: reduce slippage and also be "constrained against lateral movement along their rotational axis."
- All attachment devices (ropes, belts, chains, links, shackles, end fittings, termination means, etc)- should not fail under a load equal to six times the maximum static tension produced in normal conditions.
- User supporting surfaces- able to withstand single static load equal to a loading factor times the greater of 135kg (300lb) or max user weight without breakage.
    1. Consumer fitness equipment leading factors= 2.5
- Test load: $F_{test} = [W_p + 1.5F_a]$ S
    1. $F_{test}$= total reactionary load to be applied during test
    2. $F_a$ = max user applied load at point of user contact with machine or max capacity of machine
    3. $W_p$= proportionate amount of user's body weight being applied (or max user weight)
    4. 1.5= dynamic coefficient
    5. S= factor of safety (2.5 for consumer fitness equipment & 4 for institutional fitness equipment)
- Components that provide a resistance means and the components that transmit the load shall not fail.
    1. When cycled as intended at max user load for a minimum of 80% of range.
    2. Number of cycles at minimum= 20min of exercise * 3 times per week * 52 weeks * safety factor of 2
- Need detailed instructions if equipment requires assembly or warning for safe use.
- Details instructions for the multiple operations capable of being performed on device.

**b. Customer:**

- Variable weights and resistances.
    1. Five to thirty pounds of load.
- Contains unique features from a variety of existing devices.

- Safety release.
- Fits on the forearm of a variety of different people.
- Ideally could be used for a variety of forearm muscles and injuries.

**c. Patient-Related Concerns:**

- Failure of removable components.
- Difficult to change the weights/resistance.
- Unnecessary pain or discomfort from the device that could affect the amount of force they are willing to exert.
- Targeting wrong muscles.
- Overloading and injury.
- Difficulty inserting forearm in the device without the help of others.

**d. Competition:**

- Gyroscopic balls
- Hang Boards
    1. Don't target the extensors, but do work the forearm.
- Grip Saver by Metolius
    1. Squeezable ball with elastic finger holds to allow for flexor and extensor strengthening.
- Finger Savers
    1. Rings with slots for fingers to open up against, therefore working the extensors

## Appendix B: Suggested Exercises

1. Hold onto the handle with the palm facing downward, keeping the wrist and hand in line with the forearm
    a. Bend at the wrist down through a full range of motion (flexion) and return to the starting position
        i. Perform desired number of repetitions
    b. Rotate the hand so the palm faces upwards (supination) and return to the starting position
        i. Perform desired number of repetitions
2. Hold onto the handle with the palm facing upward, keeping the wrist and hand in line with the forearm
    a. Bend the wrist down through a full range of motion (extension) and return to the starting position
        i. Perform desired number of repetitions
    b. Rotate the hand so the palm is facing downward (pronation) and return to the starting position
        i. Perform desired number of repetitions

A suggested number of repetitions is 15-20 per exercise, per set. A suggested number of sets is 2-3.

# Appendix C: Materials Table

| Item | Part Number | Vendor | Quantity | Cost |
|---|---|---|---|---|
| 3D print L-piece and 3 Handles | N/A | UW Makerspace | 1 | $27.80 |
| 18x2" Cinch Straps with Eyelet (5-pack) | VC-18X2005E-BK | Amazon | 1 | $9.53 |
| 18x1" Cinch Straps with Eyelet (5-pack) | VC-18X1005E-BK | Amazon | 1 | $8.91 |
| Knurled Brass Inserts | 125108 | UW Makerspace | 4 | $0.40 |
| M4x8mm Screws | 125108 | UW Makerspace | 4 | $0.40 |
| Resistance Bands (3-pack) | B07Y2XXFF2 | Amazon | 1 | $9.99 |
| Memory Foam Square Sheet | B06VWV95WH | Amazon | 1 | $15.88 |
| Gorilla Glue | N/A | Free | 1 | $5.00 |

## Appendix D: CAD Drawings

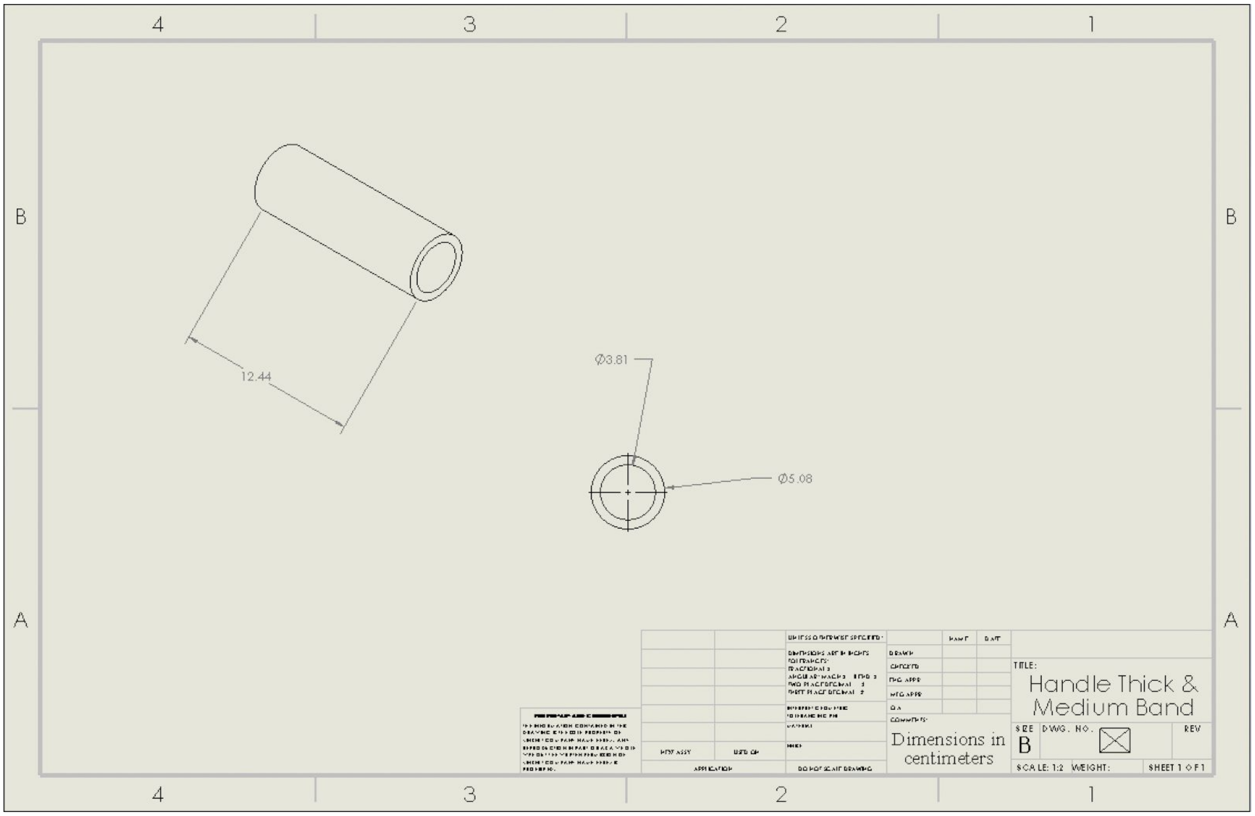


*Figure 20*: Detailed drawing of handle used for medium and thick resistance bands with dimensions in centimeters.

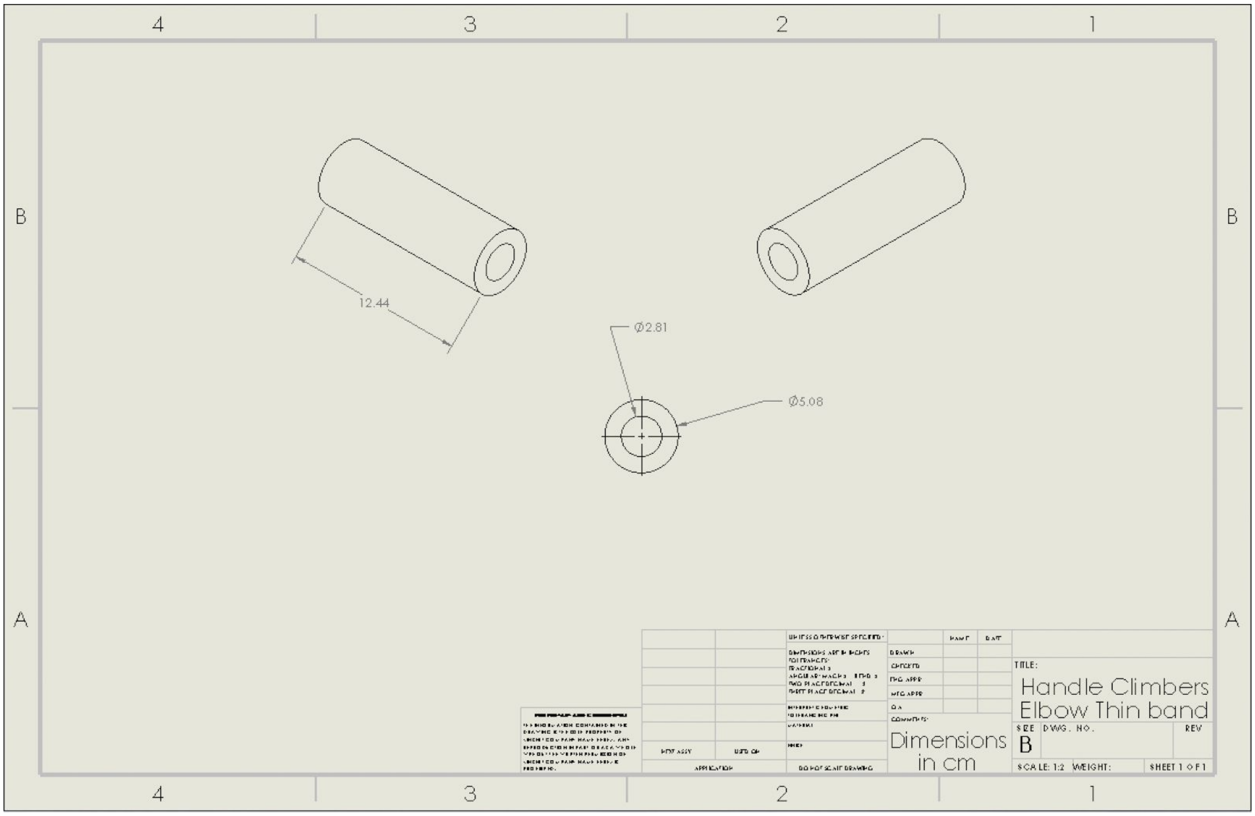


*Figure 21*: Detailed drawing of handle used for thin resistance bands with dimensions in centimeters.

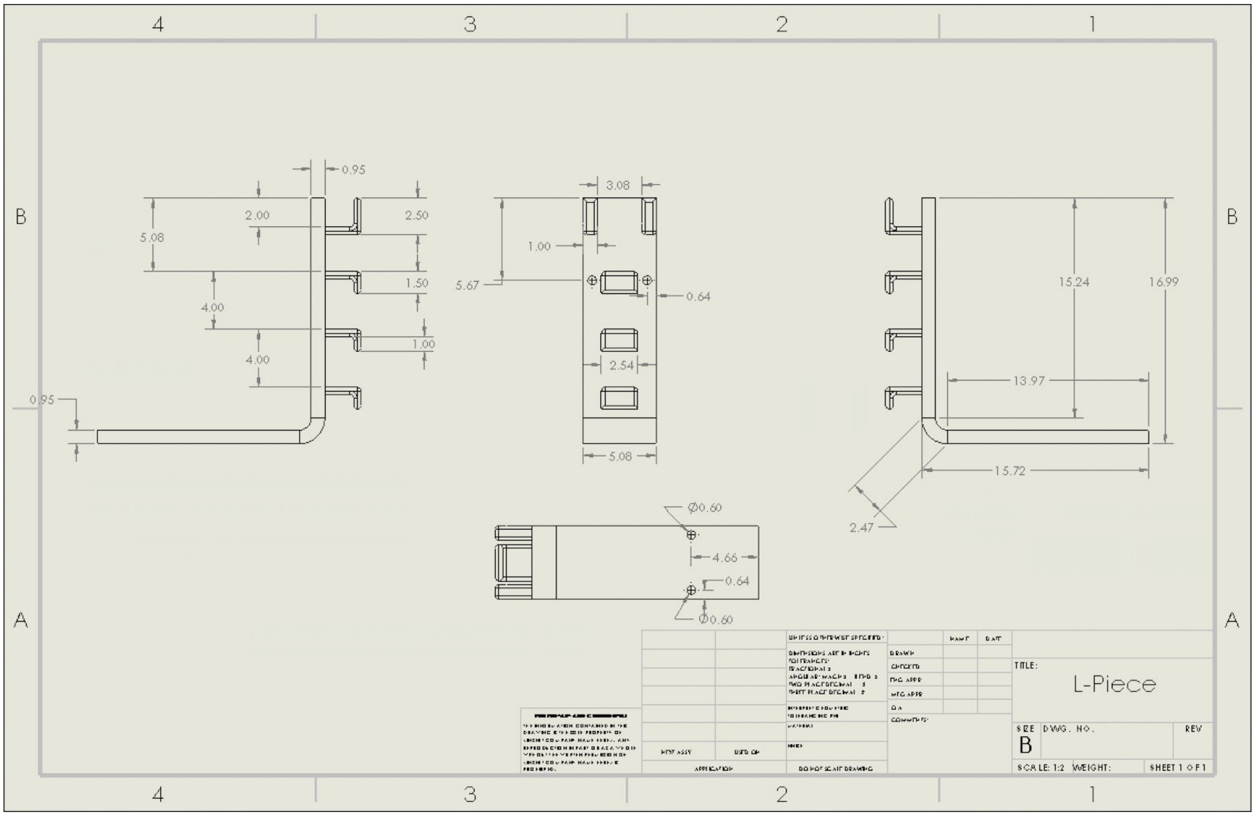


*Figure 22*: Detailed drawing of L-piece including dimensions in centimeters.

# Appendix E: Matlab Code

## 1. MTS Tension Testing

```
%% Resistance Band Testing

GreenData = load('GreenBandTest123.txt');
BlueData = load('BlueBandTest124.txt');
BlackData = load('BlackBandTest128.txt');

%Once data is decided on, percent elongation should be used using the gauge length
%for the specific trails

figure(1)
plot(GreenData(:,1), GreenData(:,2), 'g')
hold on;
plot(BlueData(:,1), BlueData(:,2), 'b')
plot(BlackData(:,1), BlackData(:,2), 'k')
xlabel('Extension [mm]')
ylabel('Force [N]')
title('Sample Curve')

figure(2)
%mm^2
%thickness * length (standard 6in)
totalAreaG = 0.3 * 152.4;
totalAreaB = 0.4 * 152.4;
totalAreaK = 0.8 * 152.4;

%mm^2
%thickness * 2cm (the size we used for the sample)
sampleAreaG = 0.3 * 20;
sampleAreaB = 0.4 * 20;
sampleAreaK = 0.8 * 20;

%Change in length (movement of crosshead) / original gauge length
pElongationGreen = (GreenData(:,1) / 1000) / 0.0762 * 100;
pElongationBlue = (BlueData(:,1) / 1000) / 0.06985 * 100;
pElongationBlack = (BlackData(:,1) / 1000) / 0.06985 * 100;

%(Force sample * total Area) / SampleArea
%Gives the force for the entire cross section not just the sample
forceGreen = GreenData(:,2) * totalAreaG / sampleAreaG;
forceBlue = BlueData(:,2) * totalAreaB / sampleAreaB;
forceBlack = BlackData(:,2) * totalAreaK / sampleAreaK;
```

```
plot(pElongationGreen, forceGreen, 'g')
hold on;
plot(pElongationBlue, forceBlue, 'b')
plot(pElongationBlack, forceBlack, 'k')
%plot(100, 38.34, 'gx')
xlabel('% Elongation')
ylabel('Force [N]')
title('Force vs. %Elongation')
```

## 2. EMG Testing

```
%% EMG Testing

GabbyDB = load('Gabby_DB_1.anc');
GabbyNR = load('Gabby_noresistance_1.anc');
GabbyRES = load('Gabby_RB_1.anc');

figure(1)
subplot(3,1,1)
plot(GabbyDB(:,1), GabbyDB(:,14),'g')
hold on;
plot(GabbyDB(:,1), GabbyDB(:,15),'r')
%plot(GabbyDB(:,1), GabbyDB(:,16),'b')
legend('Flexor', 'Extensor', 'Bicep')
title('Dumbbell')

subplot(3,1,2)
plot(GabbyNR(:,1), GabbyNR(:,14),'g')
hold on;
plot(GabbyNR(:,1), GabbyNR(:,15),'r')
%plot(GabbyNR(:,1), GabbyNR(:,16),'b')
legend('Flexor', 'Extensor', 'Bicep')
title('No Resistance')

subplot(3,1,3)
plot(GabbyRES(:,1), GabbyRES(:,14),'g')
hold on;
plot(GabbyRES(:,1), GabbyRES(:,15),'r')
%plot(GabbyRES(:,1), GabbyRES(:,16),'b')
legend('Flexor', 'Extensor', 'Bicep')
title('Resistance Band')
```

```
figure(2)

subplot(3,3,1)
plot(GabbyDB(:,1), GabbyDB(:,14),'g')
title('Dumbbell Flexor')
subplot(3,3,2)
plot(GabbyDB(:,1), GabbyDB(:,15),'r')
title('Dumbbell Extensor')
subplot(3,3,3)
title('Dumbbell Extensor')
plot(GabbyDB(:,1), GabbyDB(:,16),'b')
title('Dumbbell Bicep')

subplot(3,3,4)
plot(GabbyNR(:,1), GabbyNR(:,14),'g')
title('No Resistance Flexor')
subplot(3,3,5)
plot(GabbyNR(:,1), GabbyNR(:,15),'r')
title('No Resistance Extensor')
subplot(3,3,6)
plot(GabbyNR(:,1), GabbyNR(:,16),'b')
title('No Resistance Bicep')

subplot(3,3,7)
plot(GabbyRES(:,1), GabbyRES(:,14),'g')
title('Resistance Band Flexor')
subplot(3,3,8)
plot(GabbyRES(:,1), GabbyRES(:,15),'r')
title('Resistance Band Extensor')
subplot(3,3,9)
plot(GabbyRES(:,1), GabbyRES(:,16),'b')
title('Resistance Band Bicep')

%%
NoahDB = load('Noah_DB_1.anc');
NoahNR = load('Noah_Noresistance_1.anc');
NoahRES = load('Noah_RB_1.anc');

figure(3)
subplot(3,1,1)
plot(NoahDB(:,1), NoahDB(:,14),'g')
hold on;
```

```
plot(NoahDB(:,1), NoahDB(:,15),'r')
%plot(NoahDB(:,1), NoahDB(:,16),'b')
legend('Flexor', 'Extensor', 'Bicep')
title('Dumbbell')

subplot(3,1,2)
plot(NoahNR(:,1), NoahNR(:,14),'g')
hold on;
plot(NoahNR(:,1), NoahNR(:,15),'r')
%plot(NoahNR(:,1), NoahNR(:,16),'b')
legend('Flexor', 'Extensor', 'Bicep')
title('No Resistance')

subplot(3,1,3)
plot(NoahRES(:,1), NoahRES(:,14),'g')
hold on;
plot(NoahRES(:,1), NoahRES(:,15),'r')
%plot(NoahRES(:,1), NoahRES(:,16),'b')
legend('Flexor', 'Extensor', 'Bicep')
title('Resistance Band')



figure(4)

subplot(3,3,1)
plot(GabbyDB(:,1), GabbyDB(:,14),'g')
title('Dumbbell Flexor')
subplot(3,3,2)
plot(NoahDB(:,1), NoahDB(:,15),'r')
title('Dumbbell Extensor')
subplot(3,3,3)
title('Dumbbell Extensor')
plot(NoahDB(:,1), NoahDB(:,16),'b')
title('Dumbbell Bicep')

subplot(3,3,4)
plot(NoahNR(:,1), NoahNR(:,14),'g')
title('No Resistance Flexor')
subplot(3,3,5)
plot(NoahNR(:,1), NoahNR(:,15),'r')
title('No Resistance Extensor')
subplot(3,3,6)
```

```
plot(NoahNR(:,1), NoahNR(:,16),'b')
title('No Resistance Bicep')

subplot(3,3,7)
plot(NoahRES(:,1), NoahRES(:,14),'g')
title('Resistance Band Flexor')
subplot(3,3,8)
plot(NoahRES(:,1), NoahRES(:,15),'r')
title('Resistance Band Extensor')
subplot(3,3,9)
plot(NoahRES(:,1), NoahRES(:,16),'b')
title('Resistance Band Bicep')

%%

GraceDB = load('Grace_DB_1.anc');
GraceNR = load('Grace_Noresistance_1.anc');
GraceRES = load('Grace_RB_1.anc');

figure(5)
subplot(3,1,1)
plot(GraceDB(:,1), GraceDB(:,14),'g')
hold on;
plot(GraceDB(:,1), GraceDB(:,15),'r')
%plot(GraceDB(:,1), GraceDB(:,16),'b')
legend('Flexor', 'Extensor', 'Bicep')
title('Dumbbell')

subplot(3,1,2)
plot(GraceNR(:,1), GraceNR(:,14),'g')
hold on;
plot(GraceNR(:,1), GraceNR(:,15),'r')
%plot(GraceNR(:,1), GraceNR(:,16),'b')
legend('Flexor', 'Extensor', 'Bicep')
title('No Resistance')

subplot(3,1,3)
plot(GraceRES(:,1), GraceRES(:,14),'g')
hold on;
plot(GraceRES(:,1), GraceRES(:,15),'r')
%plot(GraceRES(:,1), GraceRES(:,16),'b')
legend('Flexor', 'Extensor', 'Bicep')
title('Resistance Band')
```

```
figure(6)

subplot(3,3,1)
plot(GraceDB(:,1), GraceDB(:,14),'g')
title('Dumbbell Flexor')
subplot(3,3,2)
plot(GraceDB(:,1), GraceDB(:,15),'r')
title('Dumbbell Extensor')
subplot(3,3,3)
title('Dumbbell Extensor')
plot(GraceDB(:,1), GraceDB(:,16),'b')
title('Dumbbell Bicep')

subplot(3,3,4)
plot(GraceNR(:,1), GraceNR(:,14),'g')
title('No Resistance Flexor')
subplot(3,3,5)
plot(GraceNR(:,1), GraceNR(:,15),'r')
title('No Resistance Extensor')
subplot(3,3,6)
plot(GraceNR(:,1), GraceNR(:,16),'b')
title('No Resistance Bicep')

subplot(3,3,7)
plot(GraceRES(:,1), GraceRES(:,14),'g')
title('Resistance Band Flexor')
subplot(3,3,8)
plot(GraceRES(:,1), GraceRES(:,15),'r')
title('Resistance Band Extensor')
subplot(3,3,9)
plot(GraceRES(:,1), GraceRES(:,16),'b')
title('Resistance Band Bicep')
```