MOTION^2

Prepared for:
Lori Bravi
Rehabilitation Institute of Chicago
Chicago, Illinois
December 5, 2015

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Executive Summary

Challenge
Due to partial paralysis of half of the body resulting from hemiplegia, some adults are unable to use products on the market to effectively strengthen and stretch their affected arms. Our client, Lori Bravi, asked our team to design an exercise device that would allow people with hemiplegia to exercise and stretch their arms despite limited control.

Purpose and Requirements
The objective of the design is to allow the user to build strength in the affected arm through multiple functions, and increase the difficulty of the exercise to match the ability of the user. The design should be safe, easy to adjust, and cost no more than $100 to make.

Methodology
In addition to interviewing the client about adults with hemiplegia and their capabilities, we interviewed a man with hemiplegia and observed him go through his range of motion to observe his strength and mobility. From this we determined the functions the user needed most in such a workout device and the muscles, which would benefit most from a new design.

Design
Our design is an arm-roller that allows the user to exercise by rolling the device along multiple different surfaces and that attaches to elastic bands for added resistance (see Table 1 below for a list of components). This lets the user exercise in gravity-neutral and gravity-supported directions.

Table 1: Components of Motion[2]

Components	Benefits
One-inch diameter, round handle	• Our user has trouble opening his hand, and this handle is easy for him to grip and hold onto for the duration of a workout
Diameter of wheels: 6 inches	• Large enough that the user's hand will not come in contact with a table or wall • Keeps device lightweight
Elastic Bands	• Allow for vertical motion of workout • Provide resistance • Can be interchanged for difficulty

Introduction

Our team was asked to design a solution to a problem for a client of the Rehabilitation Institute of Chicago: a man with partial hemiplegia seeking to improve muscle strength and flexibility in his affected arm (see Appendix A: Project Definition). Hemiplegia is the total or partial paralysis of one side of the body as a result of disease or injury to motor centers in the brain. It affects both the upper and lower body, but the effect it has varies from case to case. In cases of partial hemiplegia, muscle strength and mobility decreases, which can lead to fatigue and even falling (See Appendix B: Background Research Summary).

The user has a strong bicep muscle, but a weak triceps, and difficulty extending his arm.

Devices that are currently on the market for users with hemiplegia cannot effectively solve this problem. Many of these designs, such as arm and hand bikes, are operated with both arms and therefore do not force the user to engage the affected arm fully. Other options (i.e. forced use therapy, etc.) do focus on the affected arm, yet they only produce small improvements in the user's day-to-day life. There are also devices that can be purchased that will support the affected arm in daily life, such as the MyoPro exoskeleton. These options, however, are quite expensive and the majority of people cannot afford them.

Motion^2 solves these problems inexpensively by allowing the user to perform multiple exercises that will strengthen the user's triceps, and can also be used for stretching to increase flexibility, specifically in the shoulder area. The device has two different positions that can be used for different directions and surfaces, allowing the user different options for working out. The device is easily adjustable, and can be attached to any door without much difficulty or damage to the door.

This report covers various aspects of Motion^2 from users and requirements to specific features to future development of the design.

Users and Requirements

Primary user
Our primary user is a man with partial hemiplegia on his right side who wishes to stretch and strengthen his right arm.

Secondary users
Other people with hemiplegia, specifically patients in their first year after developing hemiplegia, who have the greatest potential to regain movement and improve arm mobility.

Requirements
The following requirements were brought up during the client interview (see Appendix C: Client Interview Summary) or created after the user observation (see Appendix D: User Observation Summary). Please refer to Appendix A: Project Definition to see which specifications of the device meet the requirements.

Safety
As the primary purpose of the device is to stretch and strengthen the user's arm, it should not harm the user during use. Since the user intends to use the device by himself, it should be safe to operate without the risk of overextending and straining any muscles.

Adaptability of Equipment
The user specifically mentioned how he was unable to continue using the same devices during rehabilitation, as they did not accommodate for his improved arm motion. A device that adjusts and adapts to the user's ability and targets various muscle groups minimizes the number of devices the user needs in order to perform different exercises over in the long term.

Ease of Use
During user observation, the user specifically mentioned his desire to use the device by himself at home and with minimal assistance from the other hand. Therefore, it must be easily operated without assistance.

Size
As the device is to be used in his apartment, it should be small and portable. It should also be sized to fit his body.

Durability
The device should easy to repair, as the user operates it in his apartment without assistance. In addition, the adjustable feature of the device prolongs the term of use. Therefore, it should last a long time.

Design Concept and Rationale

Design Description
Motion^2 aims to improve the strength and range of motion in the triceps and shoulder muscles of a user with hemiplegia. Our design addresses several of the user's requirements: it has the ability to adapt to the user's strength level and arm size, it is easy to use and store, and it is durable, making it safe to use. It features a cushioned handle, rolling rod, elastic bands, and a door attachment (see Appendix E: Bill of Materials for a more complete list of the exact materials used). The design is a combination of mockups developed from our alternatives matrix (see Appendix G: Alternatives Matrix).

The following sections describe the components of the device – axle-handle, bands, wheels, and door attachment – as well the rationale for each component.

Axle-Handle
Specifications and Use. The axle is made of an aluminum rod, 9/16 inches in diameter. The length of the rod is 14''. Wrapping adhesive vinyl foam tape around the middle of the aluminum rod forms a 6'' wide foam handle with a 1'' diameter (see Figure 1 below). The user grips the foam handle and, when performing stretches, rolls the handle along a table or wall. When using the handle for strengthening, he attaches the elastic bands to the handle.

Figure 1: Axle-Handle

Rationale. Using an aluminum rod for the axle allows the design to be lightweight, as the user had difficulty using the much heavier Arm-Roller mockup in user testing (see Appendix F: User Testing Report). The Arm-Roller features lightweight materials: A length of 14'' allows the user's arm to not to hit the wheels even when not gripping the device perpendicularly. During user testing, he indicated a preference for a cylindrical handle with a 1'' diameter. The use of a foam grip for the handle is for comfort.

Elastic bands

Specifications and Use. The bands for the device that attach the handle to the door-mounted hooks are extra-light, bulk-resistant, tube-shaped elastic bands that are 2.5 feet long. They are attached in multiples of two at a time, with one from each pair on each side of the handle (see Figure 2 below). The space on the axle allows multiple sets of bands to be attached at the same time, providing interchangeable resistance as the arm gets stronger.

Figure 2: Elastic Bands

Rationale. The elastic bands allow the user to stretch and strengthen his triceps by providing resistance when the arm is moved in a downward motion. The tubular bands have a cylindrical profile to increase durability and to reduce wear over time. Circular rings can be attached to either end to allow for easy attachment to the hooks that attach to the device. Although bands provide little resistance, the hook attaching them to the axle allows multiple sets of bands to be attached at once, and allows the user to adjust the resistance appropriate to his level.

Wheels

Specifications and Use. The econo-lite polypropylene wheels with a diameter of 6’’ (see Figure 3) are on either side of the aluminum rod. They are secured onto the axle with washers and screws.

Figure 3: a front view of one of the wheels

Rationale. The wheels are made of light plastic to reduce weight since this was the main flaw with the mockup that modeled this function (see Appendix H: Performance Testing). The non-marking polypropylene also minimizes the damage to walls or other surfaces when the product is in use. The wheels on the original mockup were too small in diameter so during user testing, the user's hand would hit the surface he was using the Arm-Roller on. The wheels are 6'' in diameter in the final prototype to account for this problem.

Door Attachment

Specifications and Use. The door attachment is a stainless steel sheet with a thickness of 0.048". It is cut and bent to fit over any door under 2 inches thick. It features two steel hooks spaced 10'' apart.

Figure 4: Door Attachment

Rationale. The door attachment allows the device to be portable, as the user can attach it to nearly any door. This allows for easy storage and use without taking up a large amount of space in our user's apartment. With the ends of the elastic bands connected to the door mount, the user can perform triceps exercises without having to anchor something to the ceiling or wall. The spacing of the hooks on the attachment is equal to the spacing of the indents on the axle. This improves the balance of the device and widens the range of possible exercises using the device.

Future Development

Our team developed Motion^2 to help our user improve mobility in his right arm. While the design covers both shoulder and triceps stretching and strengthening, there are several limitations. The following steps are recommended to further develop the design:

Further Testing

User testing. We developed Motion^2 based on observations, interviews, and testing with a user our client provided. Without working with other users, we are not sure how our device can benefit someone other than our user. Feedback from more users could help our design be more comfortable, useful, and effective. We could also test the device on people recovering from arm injuries and not just people who have hemiplegia. Experts could also be interviewed to determine which exercises maximize triceps and shoulder stretching and strengthening.

Performance testing. Testing the stretching limits of Motion^2 at the expected range of motion could help improve the safety of the device (see Appendix I: Safety Analysis). This information could help improve the life of the elastic bands, since wear will happen to them over time, and there is a limit to how far they can be stretched.

Improvements/Maintenance Issues

Currently, the device caters to almost all users, except the elastic bands have set lengths (see Appendix J: Instructions for Construction). While, there currently are only three different lengths, this does not accommodate for all doors and users of different heights (see Appendix K: Instructions for Use). An improvement may be to create some sort of adjusting mechanism that will allow for the elastic bands to change lengths as needed. The part that is most likely to break is the bands, but replacement ones do not require power tools to create (see Appendix L: Dimensioned Graphics Sketches)

Conclusion

To summarize, our design meets the key needs of men and women with hemiplegia who will use the device. The design uses a combination of:

- Multipurpose aluminum rod and Econo-lite Polypropylene wheels to create a rolling handle that is lightweight
- Elastic bands of varying tensions for resistance in rolling exercises
- S Hooks to attach the handle to elastic bands
- Over door support to keep the bands attached above the user

Adults with hemiplegia need a system that is easy to use. The s-clips will allow quick and effortless adjustment of the device for different workouts. These users will also require a device that is safe. This lightweight device, with an over-the-door mount, will not cause any harm to a potential user.

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Pedal Exercise Machine. Digital image. Aidapt Mobility Aids. N.p., n.d. Web.

Appendix A: Project Definition

Introduction
The project definition describes the purpose of the design and how it will work so the final design can be evaluated accordingly. As the project definition parallels the creation of the design, requirements and specifications (see Table A1) have changed after phases of testing and interviews. The most updated version of the project definition expresses what the design must do to meet requirements of our client and user.

Project name: Arm strengthening for users with hemiplegia
Client: Lori Bravi, Rehabilitation Institute of Chicago
Team Members: Jeff Brewer, Sophia Huang, Conor McGeehan, Marcos Schneider
Date: November 24, 2015
Version: Four

Mission Statement: To design a system that will safely increase strength and flexibility in the right arm of our user, who has hemiplegia, to help him regain functionality.

Project Deliverables: A conceptual design for a strengthening system and a model to demonstrate how it works, a final report, and a presentation of the project

Constraints:
- Must be cost less than $100 to manufacture
- Must be finished by December 5

Users/Stakeholders:
- Our primary user, John Bellefleur, a man who is afflicted with hemiplegia
- Secondary users are other people with hemiplegia (who will benefit from a new device that can help them strengthen their arms as well, specifically in the first year after developing hemiplegia)
- The Rehabilitation Institute of Chicago, a rehabilitation hospital that specializes in the treating complicated conditions

Table A1: Requirements and Specifications of the Design

Requirements	Specifications
Safety ● Final design must not endanger the user in any way	● Joints should not be overextended or strained ● Muscles must not be overstretched

	● Must be safe to operate without a spotter
Adaptability of equipment ● Must have the ability to increase resistance as the user becomes stronger ● Must be able to increase stretching range	● Resistance must have at least 2 different levels (able to be incremented) ● Stretching range must be 180° both horizontally and vertically
Ease of Use ● Must be easy to use and store ● Must be able to use independently	● The hand-held part of the device will have a mass under 2 pounds
Space/Size ● Must fit into user's apartment ● Must fit the user's arm and body	● Device will be no larger than 2 cubic feet
Durability ● Must be easy to repair	● Device will not require power tools to assemble at the location of use

Appendix B: Background Research Summary

Introduction
We conducted some background research after seeing the project description our client, Lori Bravi, an occupational therapist at the Rehabilitation Institute of Chicago (RIC), provided to gain a better understanding of our project, which is to design a workout device for a person with limited arm mobility. Our background research helped us gain a basic understanding of the problem presented, so we were better informed during our client interview. In particular, we researched: (1) basic information on hemiplegia, (2) the user, and (3) current products used to aid people with limited limb mobility.

Physiology of hemiplegia
Hemiplegia is the total or partial paralysis of one side of the body as a result of disease or injury to motor centers in the brain ("Hemiplegia"). Although it affects both the upper and lower body, the degree of affectedness varies from person to person. Some symptoms include: weakness or paralysis on one side of the body, difficulty walking, poor balance, and limited use of an arm or leg. In cases of partial hemiplegia, when the person is still able to make movements, there is a general decrease in muscle strength and mobility, which leads to fatigue and falls. As the condition affects the brain (see Figure B1), speech and visual problems may also be present.

Our user's hemiplegia developed as a result of a stroke during a surgery to remove a brain aneurysm, leaving his right side significantly weaker (Bellefleur). According to the client, the user is able to walk, but with an impaired gait and using a brace. His arm and hand have only partial movement, and he has difficulty expressing thoughts.

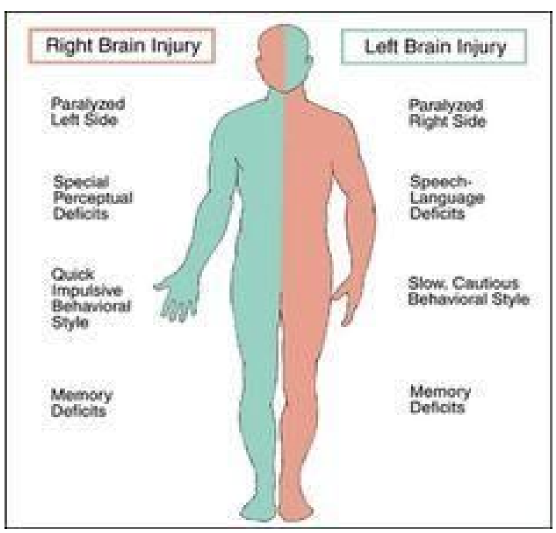

Figure B1: How brain injuries affect the rest of the body

Source:
https://s-media-cache-ak0.pinimg.com/236x/29/b3/bd/29b3bd105fbfab90c3aa5c740289b010.jpg

Background information on the user
Currently a professional photographer, our user became hemiplegic during a surgery in 2011 ("John Bellefleur, RPA"). From the project description provided by Ms. Bravi, we understand that he has worked with DTC in the past to develop a device that can assist him with his photography business. The previous DTC projects involving our user were designing a device for him to stabilize and hold his camera with one hand.

Current products/techniques used by people with hemiplegia
MyoPro
The MyoPro is a myoelectric-controlled powered arm brace (see Figure B2) that aims to help restore movement and function to the affected limb. While continued use may improve strength in the biceps and triceps, it improves only elbow movement, and does not actively strengthen muscles in the shoulder, as it only covers parts of the arm from the wrist to above the elbow (Huba). However, consistent use may help reduce maladaptive and extraneous movements such as shoulder hiking, which may occur as the user adapts to moving his or her arm after losing mobility ("How does MyoPro…").

Figure B2: MyoPro brace
Source: http://www.myopro.com/orthotists-and-prosthetists-product-details.php

Forced Use Therapy
Forced use therapy restrains the unrestricted arm to force the patient to use the affected arm to perform daily tasks (see Figure B3). To encourage purposeful, functional movement in the affected limb, therapists cast the fully functioning arm and set the patient off to go about their daily lives and learn to adapt by themselves, without specific guidance as to how to utilize the affected arm. The success of forced use

therapy tends to be in small, lasting improvements in mobility and arm use as the patient adapts to life with limited limb mobility on their own terms (van der Lee).

Figure B3: Forced use therapy in action
Source: http://www.neuro-therapie.de/images/taub-2.jpg

Pedal Exerciser
Like a stationary bike, the pedal exerciser (see Figure B4) allows the user to improve mobility in specific limbs. As it is operated with both arms, it may not strengthen the affected arm as much as in forced use therapy, and may not lead the user to accomplish daily tasks; however it is a good solution to help train muscles, as it requires repeated movement ("Home Exercise Equipment…").

Figure B4: Pedal exerciser
Source: https://www.aidapt.co.uk/images/pictures_lg/V_jpegs/VP159W.jpg

Appendix C: Client Interview Summary

Introduction
Our initial client interview was held on October 1, 2015, at 6:30 p.m. in the Ford Building. Both the client – Lori Bravi, an occupational therapist at the Rehabilitation Institute of Chicago (RIC) -- and the user were present, along with team members Marcos Schneider and Jeff Brewer. The purpose of this interview was to understand more about the current functionality of the user's arm and what problem our device should address. This appendix summarizes what we learned about the design problem (creating a device to strengthen and stretch the arms of our user, who has hemiplegia), the user, known exercise methods for muscles affected by hemiplegia, and any requirements our device must fulfill.

Design problem
The client and user emphasized that:

- The solution must allow the user to exercise and stretch his triceps, forearm, and shoulder muscles.
  - The user hopes to improve the strength and range of motion of these muscles.
  - If we are unable to target all of these muscles, strengthening the triceps should take priority.
- The goal of strengthening these muscles is not to aid in any specific task, but instead to allow the user to regain functionality in his arm.

Exercise methods
The client described exercise methods to strengthen weak muscles:

- Every muscle has a different position in which it is most effectively exercised.
- Different positioning in relation to the direction of gravity can impact the resistance of an exercise
  - It is possible to perform gravity-aided, gravity-neutral, or against-gravity exercises

User
We learned the following from having the user move his arms and the client explain what we were seeing:

- The user has a decent amount of strength in his bicep and shoulder, but his shoulder cannot move above a horizontal position on its own strength.
- The user can move his triceps and forearm muscles, but they are extremely weak.
- The user can perform triceps extensions in a gravity-neutral position, and can turn his palm upward on his own strength.
- The user has the ability to grip a handle to perform exercises.

Requirements

- The design must be able to fit into an apartment or in a storage area at RIC.
- The design must be customized for the user's body and arm size.
- The design should allow for independent exercise.
- The design must allow for increases in resistance as the user becomes stronger.
- The design must be safe for the user to operate without a spotter.

This interview gave us great insight into the design problem, information on how to exercise a muscle impacted by hemiplegia, and the requirements of both the user and client. At our user interview, we will need to take measurements of the user's arm. In addition, we will need to brainstorm and decide on multiple designs to mock up and test.

Appendix D: User Observation Summary

Introduction
On Tuesday, October 6th, 2015, Jeff Brewer, Sophia Huang, and Marcos Schneider, along with other members of DTC Section 9, met with the user in the Ford Design Center for a user observation session. He described his ideas for a solution to his problem, and participants asked questions concerning his arm strength, range of motion, and requirements for a device that would help him regain strength in his right arm. The session lasted approximately one hour. This appendix describes the methodology used to conduct the user observation, summarizes the user's physical abilities and limitations as well as his overall goals for this project, and describes the user's ideas for a workout apparatus.

Methodology
This user observation took place in a classroom of the Ford Design Center, in a group setting with members of DTC Section 9 and Professor Wood. The user first described some of the day-to-day difficulties of having hemiplegia, particularly difficulties concerning his right arm. He then detailed his idea for a device that would help him stretch and strengthen his right arm. Then he was asked about the particular strengths and weaknesses of his arm and the limitations or requirements he would have when using a workout device.

Information about the user
The user is in his 50s and has hemiplegia, which affects the right side of his body. His focus for this design project is to recuperate strength and flexibility in his right arm, so that he can extend and maneuver his arm and hand more fully. The user has participated in physical therapy for the last four years, switching between clinics, but most recently working with Lori Bravi at the Rehabilitation Institute of Chicago (RIC). He mentioned no significant improvements in his arm strength while attending the RIC, with the exception of increased shoulder strength.
The main weaknesses in his right arm are:

- Triceps
- Forearm
- Hand muscles

The user demonstrated his range of motion in his right arm as being able to lift to 90 degrees from the ground; however, he cannot fully extend his arm unless aided.

User's goals for the project
When asked to pick a specific muscle that he would most like strengthened, the user chose the triceps area. However, his ideal outcome would be to gain strength not only in his triceps, but also in his forearm. This would increase his ability to extend his arm in front of him, as if to shake hands, and also above his head, as if reaching for an object on a shelf overhead. He repeatedly mentioned his frustration at not being able to shake

hands properly anymore, due to the lack of strength in his right arm, but also due to his clenched fingers.

The user also mentioned that this device would potentially be very helpful to patients recently recovering from a stroke, seeing as most muscle function recovery occurs within the first year after a stroke or similar event. The user said he had he been able to use a device that would have stretched and strengthened his right arm during the first year after his stroke, he would have much greater use of his arm today.

User's ideas for a workout device

The user described his idea for an apparatus that would help him stretch as well as strengthen his right arm. He thinks of this device as being similar to a gyroscope, with curved tubes or bars that can be maneuvered up or down to increase reach (see Figure D1). The device consists of a large semi-circle, parallel to the ground, possibly attached to the wall so that the open half faces out towards the subject. Attached to this semicircle is a smaller full circle that the user would use to swing both up and down, using the momentum of each swing to gain greater reach, upward and downward (see area a of Figure D1). Finally, inside this full circle is another half circle that would be used primarily for stretching purposes (see smallest half tube seen in Figure D1).

The user also specified wanting to be able to complete a side-to-side motion while using the apparatus, a motion similar to turning the wheel of a car with one hand (see Table D1). This could be accomplished in two ways: by using a handle that slides along the length of one of the curved tubes, or by pivoting the entire apparatus to allow the user to move his arm in a different orientation as before.

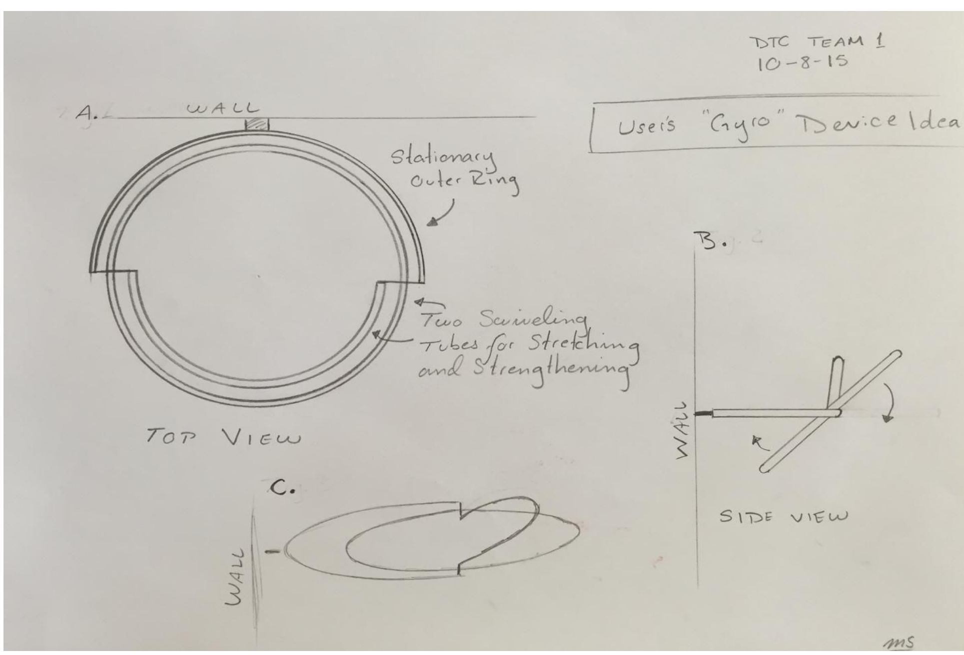

Figure D1: The user's idea for a stretching and arm strengthening device

User Observation Table

Table D1: User observation: opportunities, follow-up, and suggestions.

Observations	Opportunities	Follow-Up	User suggestions
User wants to be able to fully extend right arm.	Develop product to help user stretch right arm.	Draw on information available on safe stretching techniques.	“Gyro” bar system
User wants to be able to raise arm up and out.	Find a way to strengthen triceps.	Find out more about gravity-neutral strengthening exercises.	“Gyro” bar system
User wants to be able to turn hand over.	Find a way to strengthen forearm muscles.	Find out more about gravity-neutral strengthening exercises.	
User has difficulty/pain when gripping certain objects.	Adjust device to make holds easier.	Develop easy grips, handles, or straps for product.	

Appendix E: Bill of Materials

Introduction

The bill of materials (Table E1 below) includes all components of the final prototype. The description, quantity, part number, and unit cost allow for reproduction of the product when combined with the Instructions for Construction. Here are the materials of Motion[2].

Table E1: Bill of Materials

Item	**Description**	**Qty**	**Vendor**	**Part number**	**Unit cost**	**Total cost**
Aluminum rod	Multipurpose 6061 Aluminum -9/16" diameter -3 ft	1	McMaster-Carr	8974K46	$7.89	$7.89
Foam Tape	Vinyl Foam, Adhesive-Back -Very Soft Gray -1/4" Thick -3/8" Width -17' Long	1	McMaster-Carr	93675K13	$2.23	$2.23
Wheels	Econo-Lite Polypropylene Wheel -Black -6" x 1-1/2" -1/2" Axle -Roller Bearing	2	McMaster-Carr	2781T41	$11.00	$22.00
Washers	Mil. Spec. Flat washer -Nylon -7/16" screw size	1 (50/pack)	McMaster-Carr	92150A133	$9.40	$9.40

Axle Nuts	Low Strength Steel Thin Hex Nut -½”-13 thread size -¾” wide -5/16” high	1 (100/pack)	McMaster-Carr	90494A033	$7.42	$7.42
S Hooks	S Hook with Latch on both ends -Stainless -10lb workload -⅛” diameter	2	McMaster-Carr	6043T4	$2.76	$5.52
Elastic Bands	Bulk Resistance Tubing -25’ -Extra Light -Orange	1	Power Systems (http://www.power-systems.com/p-2699-bulk-resistance-tubing.aspx)	84451	$20.95	$20.95
Band Hooks	Orange Vinyl-Coated Steel Hook -Single Prong J shape -2⅝” projection	2	McMaster-Carr	1730A91	$2.90	$5.80
Over Door Support	Multipurpose 304 Stainless Steel Sheet -0.048" Thick - 12" x 12"	1	McMaster Carr	8983K38	$12.22	$12.22
					Total Cost	$93.43

Appendix F: User Testing Report

Purpose

The purpose of our first round of user testing was to determine which form of workout device would best suit the user. To use our design, people who have hemiplegia will need to be able to either grasp a handle or pull a sleeve over their affected arms. In this round we wanted to learn two things: (1) what form of workout device was best suited for our user, and (2) which handle was the easiest to hold while using the device.

Test methodology

All four team members conducted one user testing session with our mockups on Tuesday, October 27. The mockups were constructed of found items, including foam core, rubber bands, a sock, a balloon, wheels and an aluminum rod. The mockups varied both according to their method of exercise and the size and shape of the handle incorporated into the design. Figures F1-4 (all shown on the next page) show all of the mockups during user testing.

The tests were conducted in a classroom in the Ford Design Center at Northwestern University. The user tested each mockup both sitting and standing, and the mockups were either held by a team member or placed on a table, depending on the intended use. Our team's portion of the user testing lasted 18 minutes.
During the tests, one team member guided the user through the exercise while one member took notes, one took pictures and the fourth observed from a different angle. The user was explained the task, and then asked to use the device in slightly different ways based on feedback. The test concluded with users being asked to rate the mockups in terms of how effective the device was, and how easy the handle was to use.

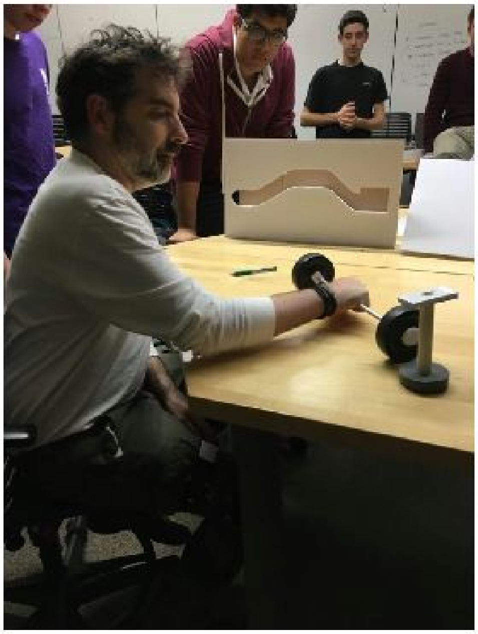

Figure F1: One-Hand Arm Roller

Handle attached to ball that rolls through the pipe.

Figure F2: Pipe System

Figure F3: Inflation Sleeve

Balloon inside of sleeve allows user's arm to be extended through inflation

Figure F4: Elastic Band

Rubber bands were used instead of elastic, and a foam ball was used for a handle

Results

The following tables (F1 and F2) summarize the user testing results. In the ratings, 1 is the worst possible ranking, and 5 is the best.

Table F1: Workout Effectiveness

Device	Effectiveness (1-5)	Comments
One-Handed Arm Roller	3	Difficult to hold parallel to the floor while pushing up
Pipe System	3	User had imagined something like this to use
Inflation Sleeve	2	His arm was already more extended than usual due to weather
Elastic Band	4	Easiest to use, particularly helpful as a downwards triceps extension

Table F2: Ease of Handle Use

Note: These rankings are based on the adjustments to the handles as suggested by the user, which were not necessarily the same handles originally on the mockups. For example, the handle in Figure F2 was removed because the user preferred the cylindrical pipe to which it was attached.

Device	Effectiveness (1-5)	Comments
One-Handed Arm Roller	4	The original handle was removed for the thin metal
Pipe System	4	The original handle was replaced with the cylinder to which it was originally attached
Inflation Sleeve	2	Long sleeves made this device hard to get on
Elastic Band	2	The user's hand was tightened up because of the weather, but he wanted a smaller handle regardless

Analysis, conclusions and limitations

Analysis of results. The user most preferred the elastic band mockup, with the band offering resistance as he performed a downwards triceps extension:

- Handle: The handle the user liked best was a cylindrical handle about 1 inch in diameter.
- Orientation: The user preferred methods where the device was at or above shoulder level.

Conclusion. The results suggest a design where the user is getting exercise in his triceps with his palm facing the floor. The design should also be stable on its own, as the user had trouble stabilizing the designs while using them.

Limitations. One limitation to our testing was that the cold and rainy weather affected the muscles in the user's hand, causing it to move in a way in would not under normal circumstances in his house. In addition, the mockups were fairly fragile and had to be held or guided by the team. This prevented the team from observing an interaction between the user and designs with no explanation or hint as to how to use them.

Appendix G: Alternatives Matrix

After a clustered brainstorming section with all of Section 9, the team combined the most promising ideas into alternative design concepts for testing before designing the final prototype. The four ideas in the matrix (see Table G1) all aimed to test different requirements outlined in the Project Definition.

Table G1: Alternatives Matrix

Alternatives	Safety	Adjustability	Ease of Use	Easy to Repair
One-Handed Arm Roller	Lightweight, not dangerous	Free-rolling wheels	Small, easy to store	Could be done with hand tools
Pipe System	No safety hazards	Track path can be changed	One-handed	Difficult open up the track
Elastic Band	Completely safe	Different heights for workouts	May be harder to set up exercises	Easy barring elastic band snap
Compression Sleeve	Could lock arm into bad position	Air pump is a quick fix	Maybe slightly hard to apply/remove	Harder to fix on your own

Appendix H: Performance Testing Report

Purpose
Of the various arm workout devices for a person with hemiplegia, the arm roller seems to be the most promising. The device's design allows for a widest range of exercises and targeting of different groups of muscles, as some of the other designs only focused on one muscle group. We wanted to determine the effectiveness of workout devices in engaging one's shoulder and triceps.

Methodology
During performance testing on Thursday, October 22, 2015, four fellow classmates participated and provided feedback on the initial mockups. Through various stretching exercises such as extending the arm to focus on the triceps and rotating the shoulder, the participants of the performance testing portion, interacted with the various devices to provide qualitative feedback. Each participant was asked to use each device in the intended manner, and was then asked to use it in a different way based on his intuition.

We obtained feedback on the ergonomics, ease of use, practicality, material composition, and flexibility of each design. We then compared the feedback of each mockup to help evaluate the overall effectiveness of each device.

Results
We learned the following from our testing of each mock-up:

<u>Pipe system (see figure H1):</u>
This mockup was a track made of foam core with a handle attached to a wheel that can be maneuvered through the track. Some areas for improvement identified in this mockup were that the transition in each turn and corner should be smooth so that the handle does not get stuck while in motion, and the handle should have a rolling attachment on the other side to smoothen the motion of the handle, a back should be attached to the track to help guide the handle, the track should be larger to incorporate more shoulder motion, the handle should be turned for user-friendliness, and the final design must be more sturdy.

Figure H1: Pipe system

<u>Arm roller (see Figure H2):</u>

This mockup was a handle with wheels on either side that can be used to perform different exercises and stretches. Some areas for improvement identified in this mockup were that it was too heavy, a ramp should be used to help the user get into the correct starting position for a shoulder stretch, the handle should be thinner to make it easier to grasp, different workouts could be done to target the triceps, and the wheels must be larger to prevent the user's hand from rubbing against the wall while performing exercises.

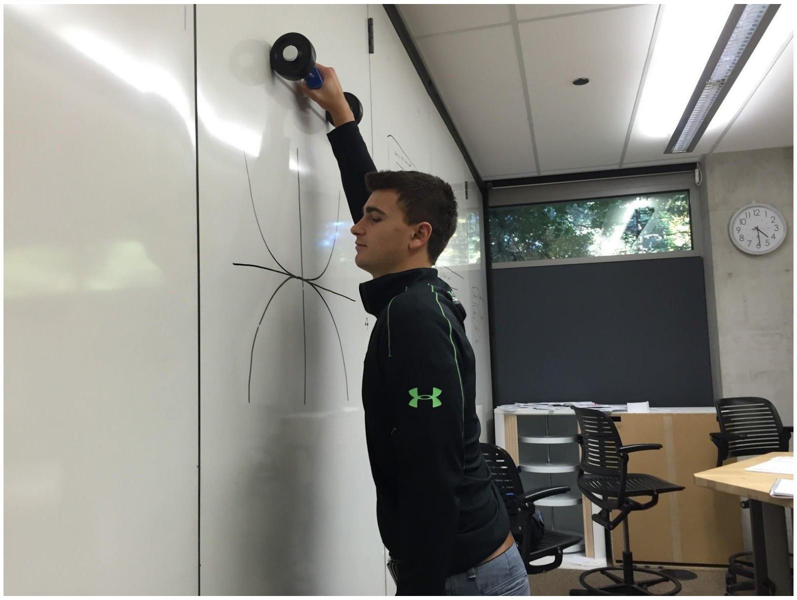

Figure H2: Arm roller

<u>Inflation sleeve (see Figure H3):</u>
This mockup was a compression sleeve that uses an inflatable balloon to aid in the extension of the user's arm, allowing him to train in a wider range of motion. Some areas for improvement identified in this mockup were that the balloon should be more securely attached to the sleeve so that it does not fall out, and that an air pump should be employed to inflate the balloon so that it does not need to be inflated by blowing into it.

Figure H3: Inflation sleeve

<u>Elastic band (see Figure H4):</u>
This mockup was an elastic band attached to a ball-shaped handle and a series of hooks to which the band can be attached. This design can be used to perform different exercises and stretches depending on where the elastic band is mounted. Some areas for improvement identified in this mockup were that the hooks should be more spread apart to allow for a wider range of exercises and motion, the elastic band should be shortened for ease of use, and different bands could be used to change the resistance of an exercise.

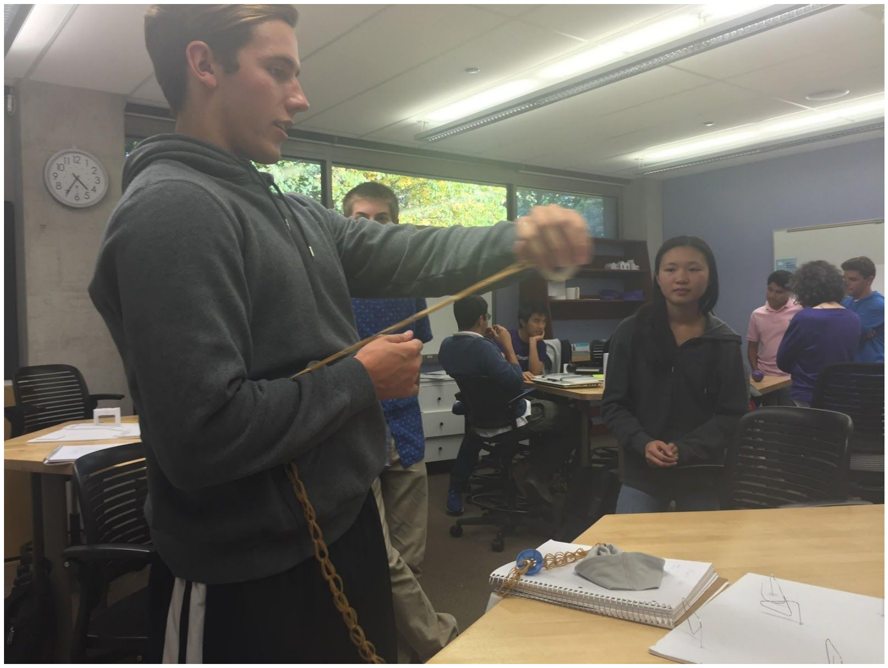

Figure H4: Elastic band

Conclusions and Limitations
The performance testing results revealed the following conclusions:

- Most mockups revealed great promise, yet materials must be taken into greater consideration for subsequent prototype. These could include lightweight wheels for the arm roller, a more ergonomic handle for the pipe system, and a better, sturdier inflation system for the compression sleeve.
- More research must be applied to the precise functions and exercises to be performed while using the devices. Specifically, with the elastic band, identifying which exercises can accomplish the greatest results.
- The full effect of the devices must be gauged based on the user's abilities. Not knowing exactly how the user will interact with each device hinders the designer's ability to test the product.

Based on performance test results, research still must be done to maximize the advantages of a device and to discover what functions the user is physically able to accomplish. These two questions can be answered through further testing, and especially user testing.

Appendix I: Safety Analysis

To ensure that the safety requirement outlined in the Project Definition is met, several use-case scenarios for each mockup were evaluated. The use-case scenarios go beyond the intended use for the mockups and evaluate how each design may be adjusted to improve its safety. These actions were taken into account when developing the final prototype after testing phases. See the following tables (I1-4) for the safety analysis of each mockup.

Table I1: Pipe System Mockup Safety Analysis

Use-Case Scenarios	Implications of the design	Options for Addressing Potential Issues	Specific Actions to Implement
Hanging objects on the handle	The handle may break as it is not designed to hold heavy objects	-Make the handle stronger -Have the handle fit loosely in the pipe, so it cannot support hanging objects	Make the handle stronger
Using the channels as a storage system for small objects	The inner track may collapse from heavy objects, breaking the device	-Make the opening for the handle smaller so the user cannot place objects inside -Rubber stop gate.	Make the opening for the handle smaller so the user cannot place objects inside

Table I2: One-Handed Arm Roller Mockup Safety Analysis

Use-Case Scenarios	Implications of the design	Options for Addressing Potential Issues	Specific Actions to Implement
Use it as a dumbbell to work out the unaffected arm	May injure the unaffected arm by performing too many strenuous exercises	-Make it light enough that this exercise would not be strenuous -	Make it light enough that this exercise would not be strenuous
Using it as a foam roller	The roller could collapse, and the user could be injured	-Shorten the length of the handle so it cannot be used as a foam roller -Make the handle uncomfortable for anything but a hand to use	Shorten the length of the handle so it cannot be used as a foam roller

Table I3: Inflation Sleeve Mockup Safety Analysis

Use-Case Scenarios	Implications of the design	Options for Addressing Potential Issues	Specific Actions to Implement
Use it to help with blood circulation	May be too tight, resulting in discomfort	-Make sure the sleeve is not too tight for the user when used correctly -Make sure the balloon does not over inflate, cutting off circulation	Make sure the sleeve is not too tight for the user when used correctly
Use it as an arm warmer	May cause the arm to overheat	-Make the sleeve out of a thin material so it does not provide warmth -Make the sleeve properly ventilated so as not to allow the arm to overheat.	Make the sleeve out of a thin material so it does not provide warmth

Table I4: Elastic Band Mockup Safety Analysis

Use-Case Scenarios	Implications of the design	Options for Addressing Potential Issues	Specific Actions to Implement
Tie objects together	The band might get damaged	-Make band in a shape that is difficult to tie knots in -Make band durable so it does not get damaged	Make band durable so it does not get damaged
Can be used as a whip	Could lead to injury especially when swung towards face	-Make the device light so it causes little damage -Make the material soft so no damage will be inflicted.	Make the device very light so it causes little damage,

Appendix J: Instructions for Construction

Table J1: Material List

Material	**Specifications**	**Quantity**
Aluminum Rod	-9/16” diameter -3 ft length	1
Wheels	-6" x 1-1/2" -1/2" Axle	2
Washers	-1/2” ID -1” OD	4
Screws	-1/4” -20 thread -1/2” length	4
Nuts	-1/4” -20 thread	2
Steel Sheet	-12” x 12” x .048”	1
Wood Block	-2” x 2” x 12”	1
S Hooks	-1/3” diameter -10 lb workload -Dual latches	2
Elastic Resistance Tubing	-light resistance -25’	1
Wall Hooks	-2-5/8” projection	2
Hockey Tape	-2’	1
Nylon rod	-1-1/2” diameter -5” length	1
Foam pad	-¼’’ thick -2’’ wide -12’’ long	1
Foam tape	-1/4" Thick -3/8" Width	1

	-17' Long	

Note: See Bill of Materials for detail on cost, part numbers, and vendors.

The following are the tools needed to construct this device:

- Lathe
- Flat head screwdriver
- Center drill
- F drill bit
- 1/4“ 20 thread tap
- Hand saw
- File
- Water jet cutter
- Manual bending brake
- Drill press
- Phillips head screwdriver
- Hot glue gun
- X-Acto knife

<u>Constructing the Roller (see Figure J1 for completed roller)</u>

1. Use the lathe to decrease the diameter of the aluminum rod to .5 inches at each end to fit the wheels
2. Use the lathe to cut into the aluminum rod to create grooves for the S-hooks
3. Use the lathe to center drill, drill with the F drill bit, and tap each end of the rod 1 inch deep
4. Use the lathe to decrease the thickness to .5 inches and the diameter to 5.5 inches
5. Use the lathe to decrease the outer diameter of the nylon rod to fit into the wheels
6. Use the lathe to center drill, then drill with a 17/32 drill bit into the nylon rod
7. Use the lathe to cut 4 .5 inch wide bearings out of the nylon rod
8. Put the new bearings into the wheels and mount them on the axles with washers on either side
9. Screw the 1/4“ 20 thread screws into the ends of each axle to hold the washers in place
10. Wrap the foam tape around the center of the axle.
11. Wrap hockey tape around the foam.

Figure J1: finished arm roller

Constructing the Door Mount (see Figure J2 for finished door mount)

1. Use the water jet to cut out two ½ inch diameter holes placed 2 inches from the sides of the metal, and 1 inch from the bottom.
2. Use the water jet to cut out three rectangles, each 4 inches wide. This step is not essential, however it makes the bending process much easier.
3. Bend the metal sheet into a U to fit over a door, with a lip coming out and down to fit the spacer block. All bends are made at 90˚.
4. Drill two holes in the wood block that match the position of the holes in the metal brace. The holes should be slightly larger than the screw in order to let them slide in without difficulty.
5. Drill to larger whole in the back of the wood block on top of the smaller holes. These fit the nuts.
6. Assemble the door mount by screwing together the hooks, metal brace and wood block, all fastened in the back with the nuts.
7. Use a hot glue gun to attach the foam backing to the wood block where it will make contact with the door.

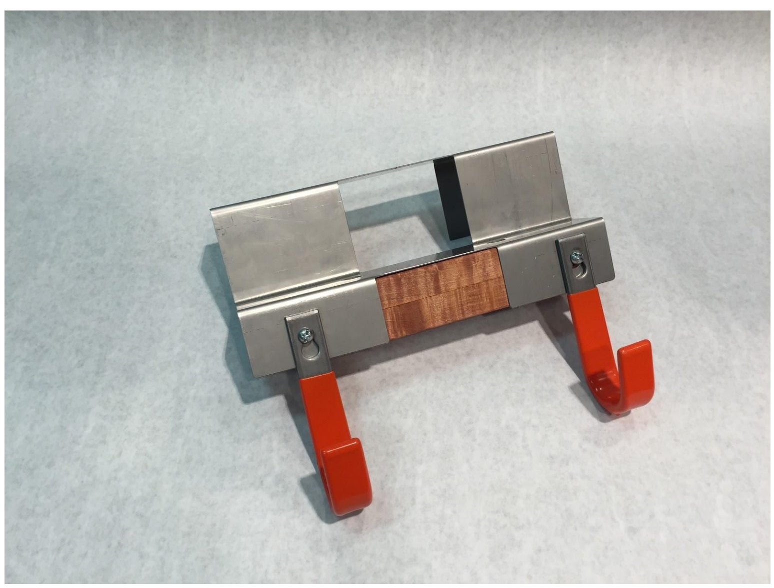

Figure J2: completed door mount

Constructing the Elastic Bands

1. Use an X-Acto knife to cut the roll of elastic to different lengths and thicknesses

2. Create a loop at each end of the band using a zip tie

Appendix K: Instructions for Use

For shoulder stretches

Along the wall

1. Grasp the handle of the roller and align the wheels with the wall while standing an arm-length away from the wall (see Figure K1).
2. Step into the wall while exerting force upwards to help roll the device upwards (see Figure K2).

Figure K1: initial position for shoulder stretches

Figure K2: performing the stretch

On the table

1. Grasp the handle and place the device on the desk, making sure that the forearm is parallel to the table
2. Extend the arm and lean forward, allowing the device to roll forward and the shoulder to stretch out (see Figure K3).

Figure K3: using the arm roller on a table

For triceps stretches

Initial setup

1. Attach the elastic bands to the hooks on the door attachment before placing the door attachment over a door (see Figure K4). Be sure to shut the door before performing the exercise.
2. Attach the desired number of elastic bands to the roller by placing them through the S-hook. Then place the hook into the notches on the rod (see Figure K5).

Figure K4: initial band setup

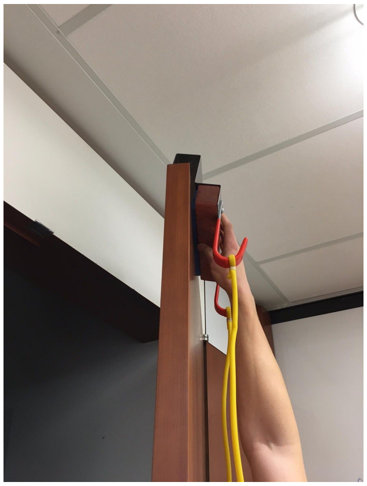

Figure K5: placing the door attachment

Stretching

1. Grasp the handle on the roller and bend the elbow 90° (see Figure K6).
2. Extend the elbow and move the roller downward against the elastics to stretch the triceps (see Figure K7).

Figure K6: attaching the bands to the rod

Figure K7: performing the triceps exercise

Appendix L: Dimensioned graphics sketches

The following Figures (L1-5) showcase the sketches of the final product in the various components and views.

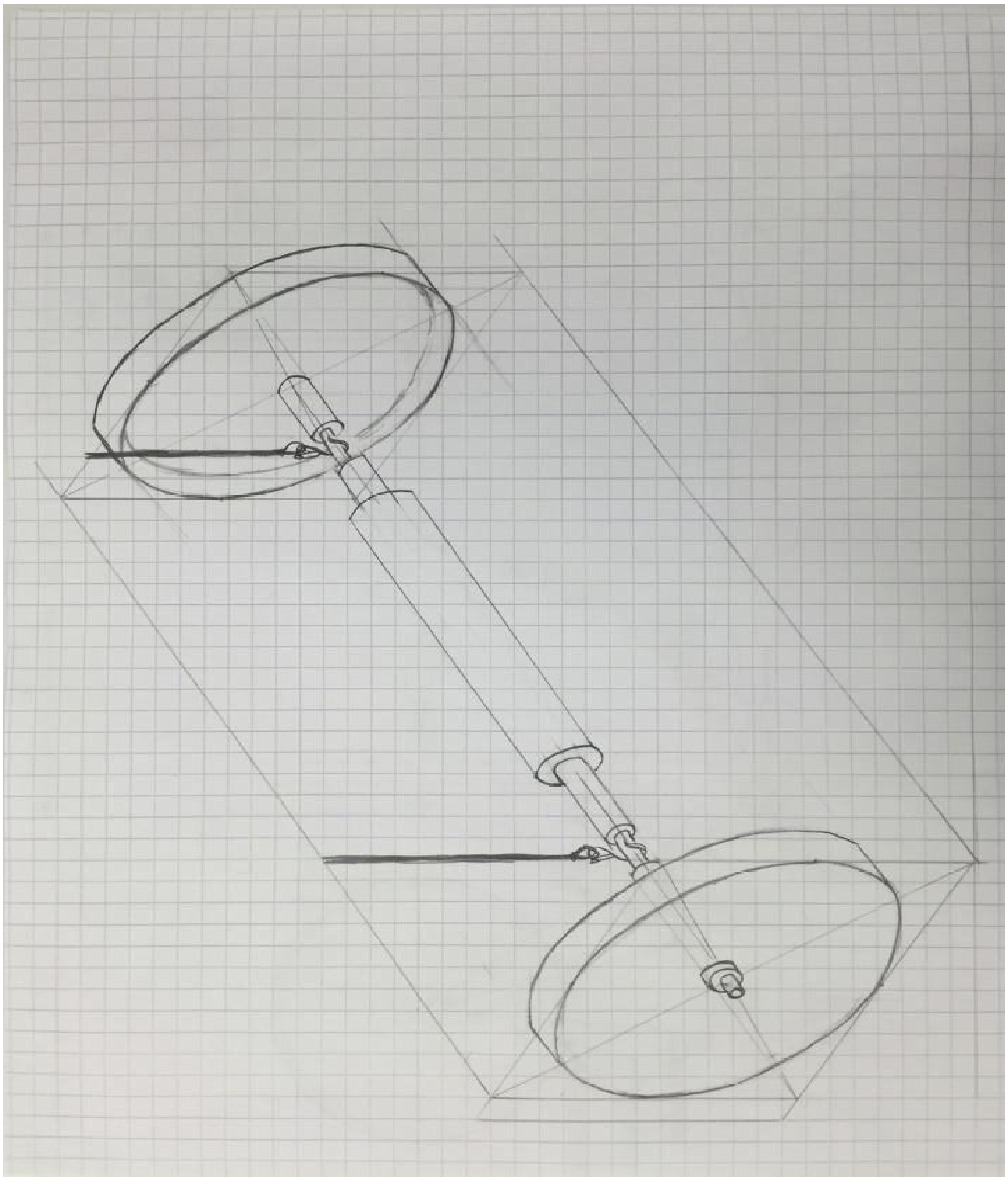

Figure L1: Isometric view of the Arm-Roller with elastics attached

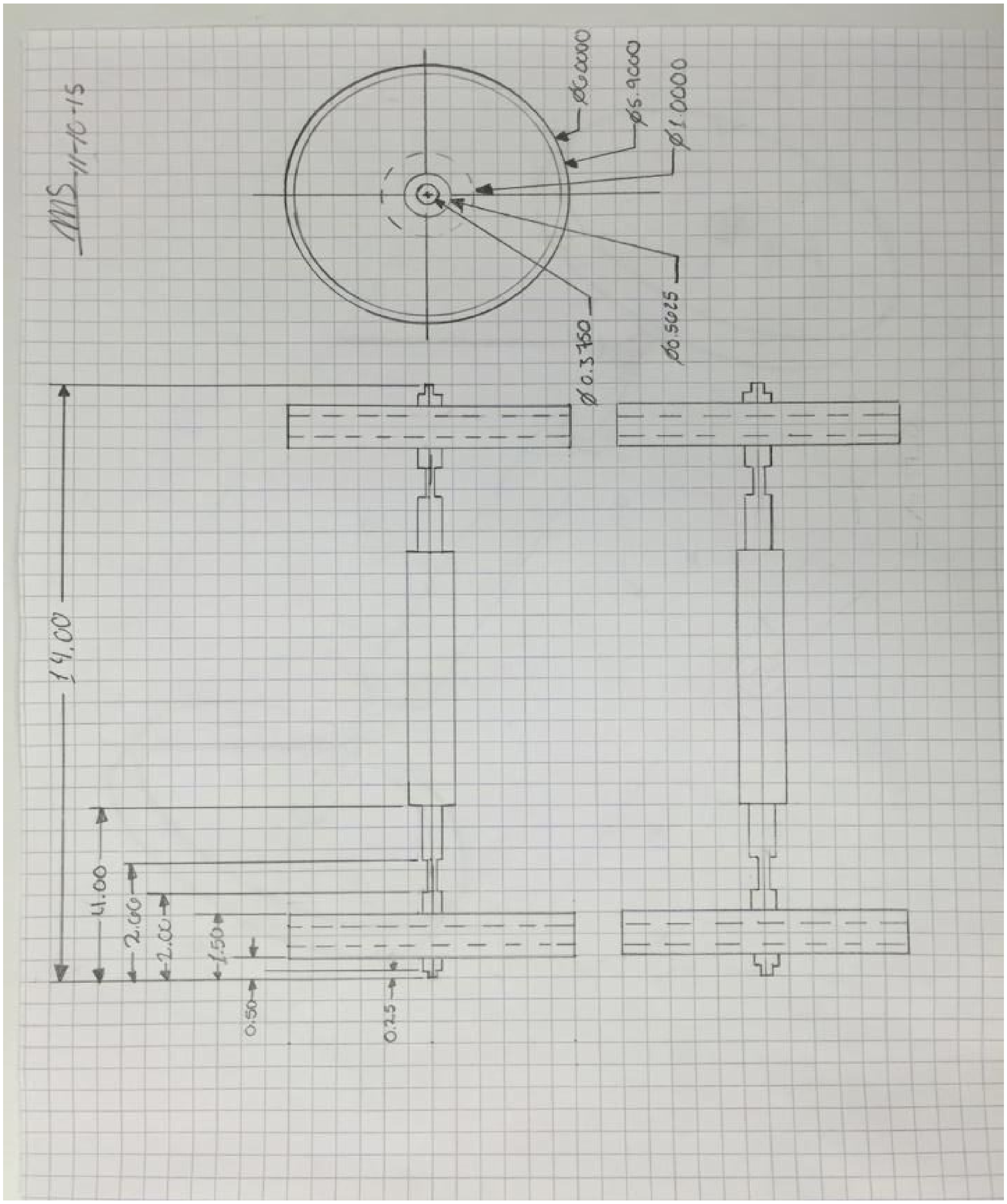

Figure L2: Orthographic view of the Arm-Roller

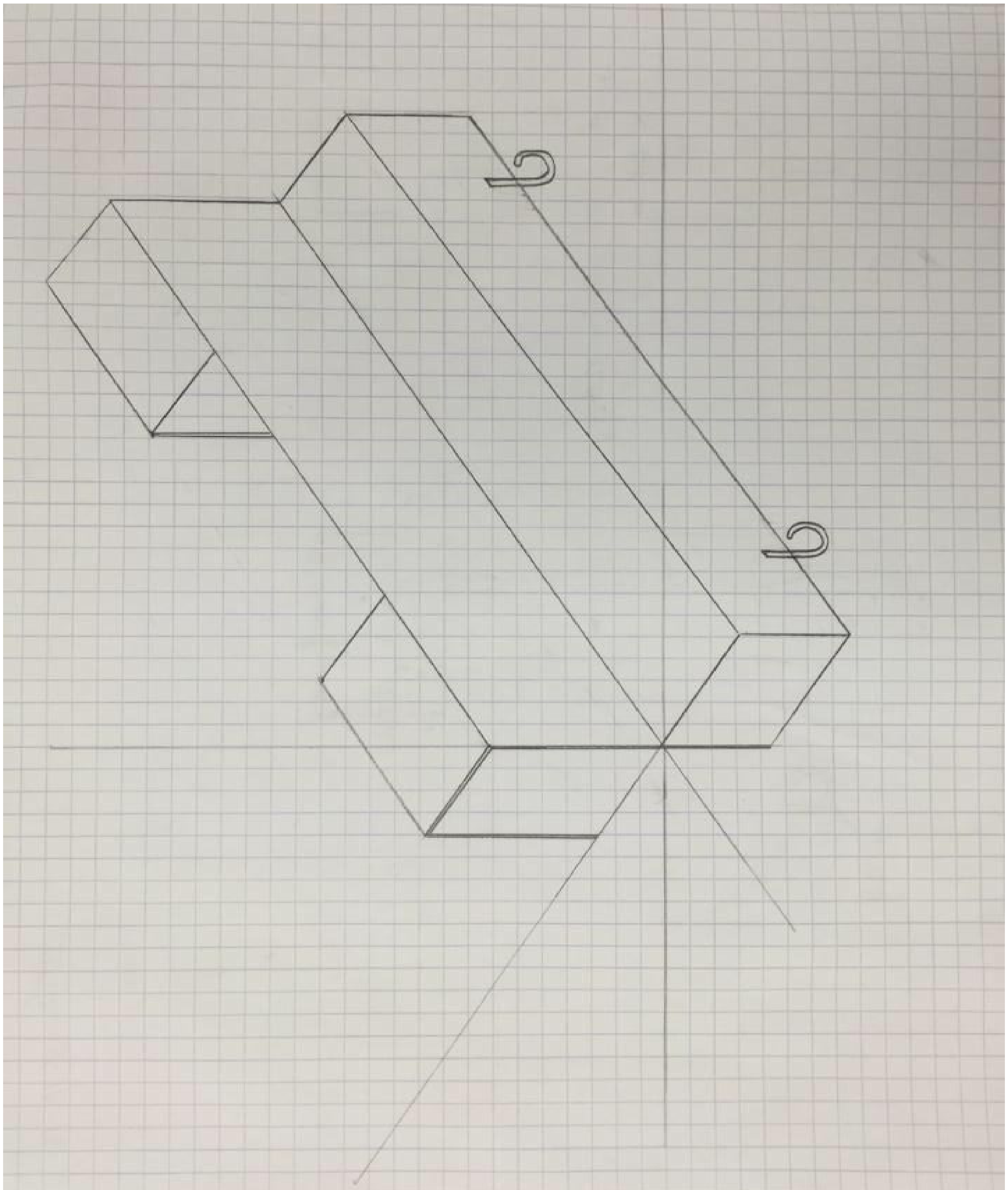

Figure L3: Isometric view of the door attachment

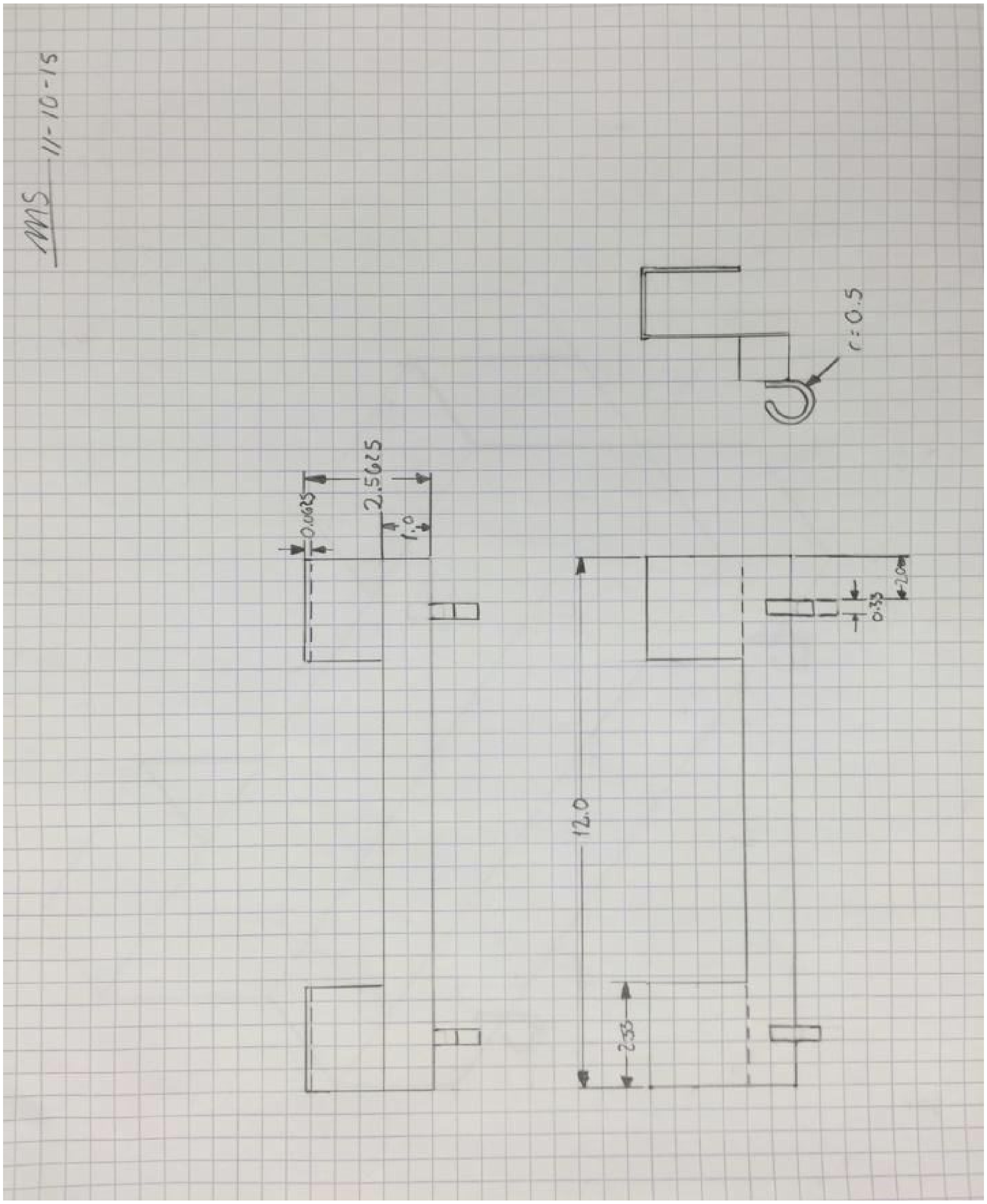

Figure L4: Orthographic view of the door attachment

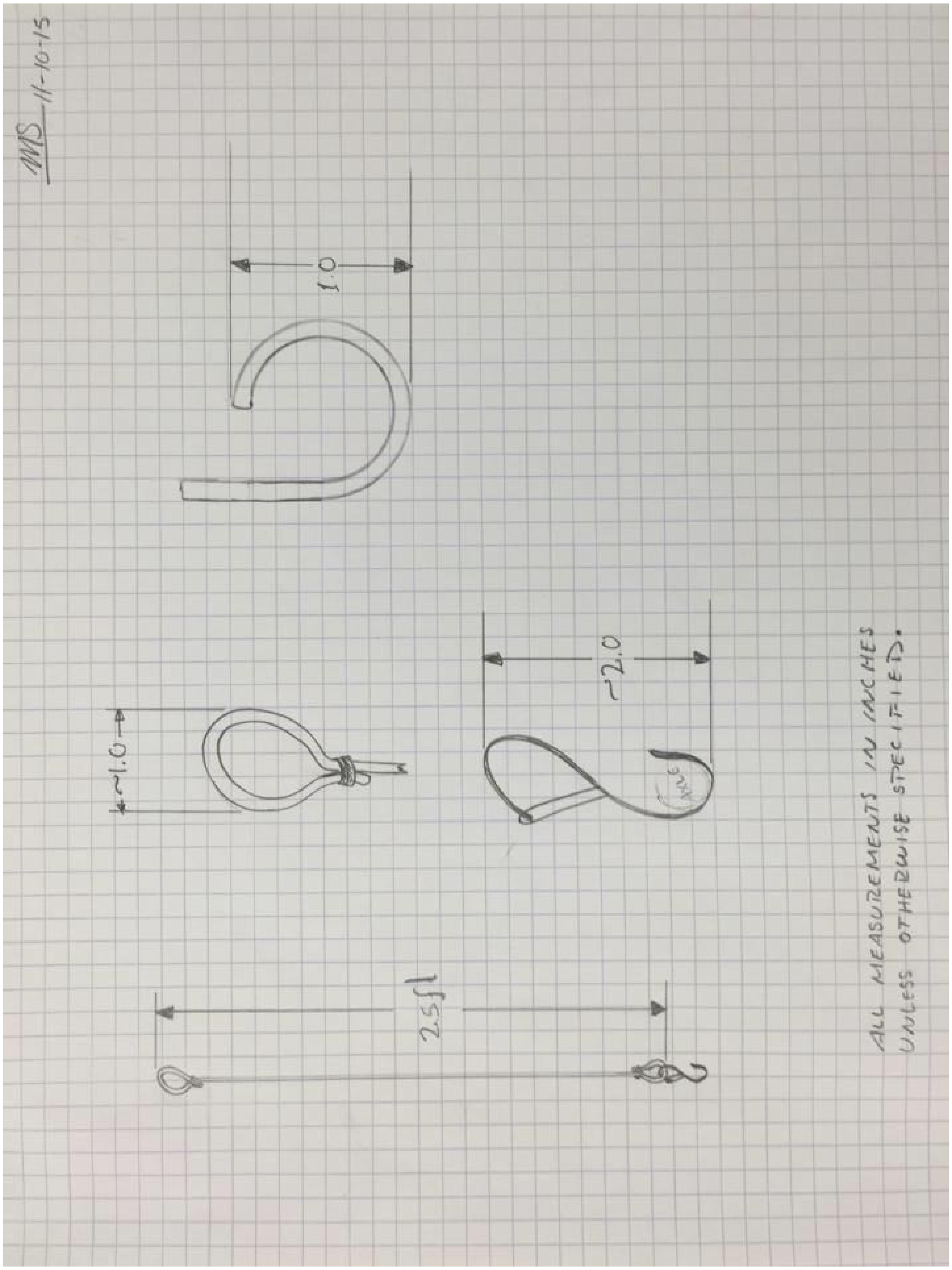

Figure L5: Sketches of the various hooks used in the design