Final Design Report: Armrest for Stroke and TBI Patients

Prepared for:

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EXECUTIVE SUMMARY

Stroke and TBI patients often experience paralysis or weakness on one side of their body, which can lead to poor posture and shoulder subluxation if not treated correctly. Our client, Courtney Celian of the Shirley Ryan AbilityLab, asked us to design a wheelchair armrest that is easy to use, stable, and useful in the rehabilitation of stroke and TBI patients.

We interviewed occupational therapist Courtney Celian and observed one of her patients to understand their therapeutic needs and the drawbacks of current armrest designs. Implementing our observations, we built three mockups of different designs and received feedback from a user at the AbilityLab. Additionally we conducted performance testing on the mockups to then design our final prototype.

The Adjust-a-ball Armrest is a padded arm-trough with an elbow-fitted back, mounted atop a locking ball and socket joint that is secured by cushion u-bolts to the wheelchair frame (Figure 1). Our design meets three main requirements that we established through research, interviews, and testing:

- Ease of use: All of the armrest's functionalities can be adjusted through a single knob. Due to the two part construction, the arm trough can be removed within three seconds, which is vital for patient transfers.
- Secure attachment: The mounting piece utilizes three cushion u-bolts to attach to the wheelchair, ensuring zero slippage when used by the patient. The arm trough is also constructed of aluminum and steel for durability and strength.
- Aid in rehabilitation: The ball and socket mechanism provides upward and lateral mobility to helps treat edema and hypertonia. The side cut-out on the arm trough positions the elbow directly below the shoulder for optimal support, which prevents shoulder subluxation.

Figure 1. The Adjust-a-ball Armrest utilizes a ball and socket mechanism to allow for rotation of the padded arm-trough.

INTRODUCTION

Stroke and TBI patients often experience paralysis or weakness on one side of their body, including their shoulder and arm. When not treated correctly, this can result in worsening condition, poor posture, and shoulder subluxation. Symptoms can be mitigated by correctly positioning the patient's arm as they sit in their wheelchair, so, patients who are recovering from a stroke or traumatic brain injury (TBI) often need an armrest that encompasses comfort, prevention of further injury, and usefulness in rehabilitation (see Appendix A).

Currently, the Shirley Ryan Abilitylab uses three types of armrests:

Slide-on Arm Trough:

> While it is easy to slide on and off the wheelchair, it is not very secure. It is often positioned too far to the side, and smaller patients are forced to lean over in order to keep their arm on the trough, which can lead to postural deformities.

The Screw-on Armrest:

> It is very difficult for the user to remove the armrest from the wheelchair. Also, the screws strip and come off very easily ruining the armrest's structural integrity.

The Half Lap Tray:

> Due to its size and poor attachment, it tilts or falls off under the weight of a larger patient's arm.

Our design, the Adjust-a-ball Armrest, addresses the three main concerns brought up by these existing designs: ease of use, security and stability, and rehabilitation and therapeutic functionality. Our design incorporates a well padded arm trough, which allows for comfort for different arm sizes, and the ball-socket mechanism underneath the arm trough is able to rotate in any direction to assist patients in their rehabilitation process. When locked in place, the armrest can hold up to seventy-five pounds of weight, which ensures a stable place for patients to rest the arms. The armrest also allows for secure attachment onto the wheelchair using cushion u-bolts, which can easily be removed from the wheelchair when needed.

This report explains the users, requirements, and specifications of the current designs, along with a detailed explanation of how the Adjust-a-ball Armrest addresses the problems with the current products. We conclude with our design's limitations and recommendations for future testing.

USER NEEDS AND REQUIREMENTS

MAIN USERS OF THE DESIGN

Stroke and TBI patients

Our main users are stroke and TBI patients. Because strokes and TBI can cause a change in the tone of one side of a person's body, it is a necessity that the armrest be able to maneuver and hold the arm of the patient. As found in our research, if the arm is not properly positioned, the patient may experience postural deformities and shoulder subluxation (see Appendix B).

Therapists and Caretakers

Patients and therapists alike both need this design as a means to use the armrest as a physical therapy device. This product will both aid the therapist in their pursuits of rehabilitation and also the patient as the continue to progress on their road to recovery. Similarly people who care for patients after their time at the Shirley Ryan Abilitylab will have an easier time operating the device and also will be able to use it to replicate and continue to practice the methods of the therapist.

REQUIREMENTS

Our design aims at fulfilling three major requirements:

Must be easy to use

In the client interview, the client stated that patients value comfort over all other requirements, so the design must be comfortable (see Appendix C). The client also requested that the armrest must be easy to clean, so that the armrest can be quickly wiped down and reused.

Must be secure and stable

One of the main issues with the current armrests in the Abilitylab presented during the client interview is that they fall off very easily due to a lack of security or are easily broken due to the weight of the patient's arm (see Appendix C). The design must be able to hold the full weight of the patient's arm, no matter how heavy their arm may be. It must also be attached securely onto the wheelchair to keep the patient's arm in place and prevent further injury (see Table 1).

Must be able to rotate vertically and horizontally

Background research has shown that the main function of these armrests is to assist patients in their rehabilitation process, which includes moving their arms to different angles and positionings (see Appendix B). This means that the armrest must be able to rotate in different directions to help patients stretch their arms.

DESIGN DESCRIPTION AND RATIONALE

DESCRIPTION OF THE DESIGN

Our armrest design is a padded arm-trough with an elbow-fitted back mounted atop a locking ball and socket joint, secured by clamps to the wheelchair frame (Figure 2).

Figure 2. A side view of the armrest prototype.

It consists of two parts:

1. the arm-trough that is bolted to the ball and socket mechanism
2. the mounting piece, a short aluminum rod that remains fixed to the wheelchair frame

The aluminum rod fits into the ball and socket mechanism of the armrest and the two pieces can be securely joined by tightening the knob on the mechanism.

The orientation of the arm-trough can be adjusted by loosening the knob, moving the arm-trough to the desired position, and retightening the knob. It can be angled both upward and orbitally in relation to elbow (Figure 3).

Figure 3. The Adjust-a-ball Armrest can be rotated both vertically and horizontally.

DETAILS OF EACH FEATURE

Arm Trough

This part of our design interacts most directly with the user and is integral to the user's comfort. The arm trough consists of various parts (Figure 4):

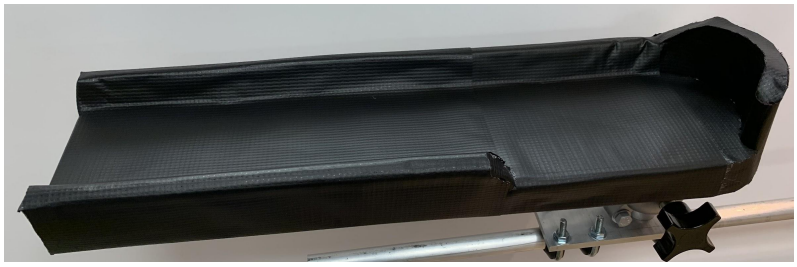

Figure 4. A close-up view of the arm trough.

- A flat bottom to accommodate for a wide range of arm sizes, as requested by our client Courtney Celian during the client interview (see Appendix C)
- A section cut out from the side of the trough on the user's torso side so that the armrest does not dig uncomfortably into the user's arm, keeping the elbow comfortable and close to the user's side, which, as found in our research, is important for rehabilitation (see Appendix B)
- Multiple sets of threaded holes set an inch apart each on the bottom of the arm-trough, allowing the ball and socket mechanism to be adjusted horizontally in or out to accommodate for users of different sizes as requested by the client during the client interview (see Appendix C)
- Arm trough is wrapped in treated polyester fabric, a material that is comfortable, durable, affordable, and easy to clean, which are all requirements given by our client during the interview (see Appendix C)

Ball and Socket

This mechanism creates the therapeutic functionality of our design. The ball and socket has several key features (Figure 5):

Figure 5. A close-up view of the ball and socket joint.

- It allows for the orientation of the arm trough to be adjusted through both vertical and horizontal rotation, which was found in our research to be necessary for rehabilitation (see Appendix B)
- The initial ball and socket design was not sturdy enough when significant force was placed on the armrest by the user during the user testing (see Appendix E)
- It utilizes a wood carving vice for the ball and socket, tested in our performance testing to be able to hold up to 40 pounds of weight at the tip of the armrest and advertised as capable of supporting 75 pounds of weight (see Appendix F)
- The mechanism can be rotated in all directions when the tightening bolt is loose and locked in place when the bolt is tightened
- The ball and socket sits directly beneath the patient's elbow, keeping the elbow stationary and supported, no matter the position of the arm-trough

Mounting Piece

This is the part of our design that allows the mechanism and arm-trough to be securely attached to the wheelchair at most times. The mounting piece consists of several features (Figure 6):

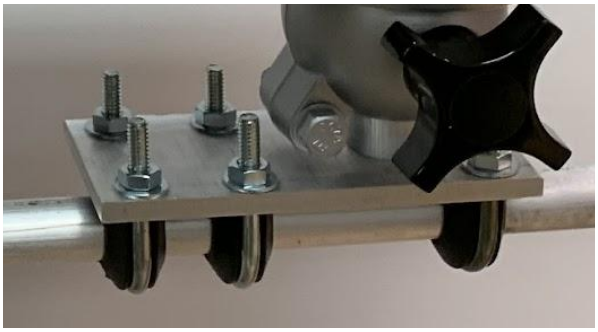

Figure 6. The mounting piece of the Adjust-a-ball Armrest uses three u-bolts connected to a metal plate to secure it onto the wheelchair.

- There are three cushion u-bolts connected to a metal plate, which is then attached to a short one-inch diameter aluminum rod
- The multiple cushion u-bolts design, which utilizes rubber to mitigate rotational slippage from torque created by the patient, ensures that the armrest is fixed tightly onto the frame of the wheelchair
- The arm trough can be detached from the mounting piece in seconds with the ball and socket mechanism, making it convenient for the therapists, as requested by the client (see Appendix C)

REQUIREMENTS AND HOW THEY'RE MET

Ease of Use and Accessibility

Must be comfortable

During the client interview and the user observation, an emphasis was placed on the user's comfort above all other requirements (see Appendices C and D). Our design incorporates a well-padded arm trough with a back pad to fulfill this requirement. Furthermore, it includes a flat base allowing for different arm sizes to be able to sit comfortably in the armrest. In addition, the design allows the armrest to be adjusted vertically depending on each patient's arm length from the shoulder to the elbow.

Must be easy to clean

During the client interview, the client also mentioned that the armrest must be easy to clean (see Appendix C). Our design uses treated polyester fabric so that the armrest itself can be cleaned easily. This will allow the user to wipe the armrest down quickly using a bleach cloth.

Security and Stability

Must be able to hold the full weight of a patient's arm

In order to fulfill this requirement, performance testing was done to ensure that the design could hold the average weight of an arm (see Appendix F). The mechanism withstood 40 pounds of weight being placed at the very tip of the armrest, but the maximum weight capacity of the actual mechanism is advertised to be 75 pounds. We could not test higher than 40 pounds simply due to the relative weakness of the plywood. The ball-socket was deemed too small to hold the weight of an armrest and the patient's arm, so the final design uses a larger mechanism, which has been tested to be able to hold over forty pounds at the end of the armrest without slipping.

Must be attached securely to the wheelchair

User observation brought to our attention the issue of secure attachment to the wheelchair (see Appendix D). To ensure that the armrest securely attaches to the wheelchair, the final design uses three cushion u-bolts to keep the armrest fixed. This allows it to stay secured to the wheelchair without tilting sideways. However, it can also be taken off the wheelchair easily by unscrewing them.

Rehabilitation & Therapeutic Functionality

Through our background research and the client interview, we learned that the positioning of the patient's arm was crucial to the rehabilitation process (see Appendices B and C). In order to fulfill this requirement, our final design incorporates a ball-and-socket mechanism that allows the armrest to rotate vertically and horizontally.

This feature facilitates the patient's need to stretch their arm and chest muscles, aids in resistive training to boost muscle tone, and prevents shoulder subluxation. The user can easily change the position of the armrest by loosening the screw that locks the ball-socket mechanism in place. After adjusting the armrest to the desired position, the user would simply tighten the screw again to lock it in place.

LIMITATIONS AND NEXT STEPS

LIMITATIONS

Ease of Use

- Our current design includes a small metal piece that remains permanently attached to the wheelchair by multiple U-bolts. It can be time consuming (though not technically challenging) to remove.
- The position of the adjustment screw for the ball and socket mechanism is in a position that may be hard to reach.

Security and Stability

- The current attachment method, padded U-bolts, is only effective within a small range of pipe diameters. Future designs should allow for more flexibility, as wheelchair frames do not have three-quarter-inch diameter, standard-sized tubes.

Rehabilitation and Therapeutic functionality

- Our arm-trough has a padded back, so the elbow sits a small distance forward from directly below the shoulder. Ideally, the elbow should be directly below the shoulder.
- To accommodate the large ball and socket mechanism, the armrest sits a 3-4 inches above the armrest provided with the wheelchair, which may be too high for smaller users.

FUTURE DEVELOPMENT

The following steps are recommended to develop our design in the future.

Further Testing

User Testing. The Adjust-a-ball Armrest was developed based on a series of observations, interviews, and testing with one user whom we were introduced to by a therapist at the Shirley Ryan Rehabilitation Lab in Chicago. More feedback from more users could provide more insight into greater demographic's needs that would help improve the effectiveness of our product. Also, our product should be tested with people of various sizes to see how their comfort is affected.

Performance Testing. We were able to test the weight capacity of our product to a large extent, but we would like to test until breaking to see how much force our product can hold due to force provided by the patient. This would help us improve the durability and functionality of our product.

Improvements to the Design

Form Fit. Creating an armrest that was more fitted to each individual patient's arm would greatly increase the comfort of our product. By doing this the arm would remain more stationary in the rest and similarly make the experience of using the rest more enjoyable.

Height. Decreasing the height difference between the armrest provided with the wheelchair and our armrest will make our product more comfortable. The positioning of the arm with respect to the body is currently slightly awkward due to height and could largely benefit by being moved down.

CONCLUSION

To summarize, our design meets the key needs of stroke and TBI patients who will use our armrest to facilitate their rehabilitation process. The design consists of the following key features that meet the requirements given by the client and user:

- The flat bottom and cut-out side part on the arm trough accommodates for all arm sizes
- The treated polyester fabric wrapping on the arm trough ensures comfort and ease of cleaning
- The ball and socket mechanism allows for upward and sideways adjustment, which is critical for rehabilitation purposes
- The wood carving vice that is used for the mechanism can hold up to 75 pounds, which is enough to support the weight of the user's arm
- The ball and socket is placed directly under the patient's elbow, allowing the user to maintain correct posture while sitting
- The mounting piece has three rubber cushion u-bolts, which prevents rotational slippage and keeps the armrest locked in place
- The arm trough can be detached in seconds with the ball and socket mechanism, making it convenient for therapists

Our client, Courtney Celian, emphasized easy attachment, accommodation for all arm sizes, ease of cleaning, and lateral rotation and upward tilt for rehabilitation as her main requirements. Our armrest design meets the requirements of the client with its easily removable ball and socket mechanism and flat bottom, polyester fabric arm trough.

Our users, the stroke and TBI patients at Shirley Ryan Abilitylab, wanted an armrest that featured comfort, elbow support, secure attachment to the wheelchair, and therapeutic functionality. Our armrest design meets the requirements of the user with its polyester fabric arm trough, a ball and socket mechanism that rotates orbitally in relation to the elbow, and cushion u-bolts to keep the armrest locked in place.

In conclusion, our armrest, which consists of the arm trough, ball and socket mechanism, and mounting piece, meet all the requirements stated by both the client and user.

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APPENDIX A: PROJECT DEFINITION

Project name: Wheelchair Armrest for People Who Have Had a Stroke or TBI
Client: Courtney Celian, Shirley Ryan AbilityLab
Team members: Jennifer Chiang, Sean Lee, Peter Tuchler, Alec Greenwald
Date: October 30, 2019
Version: Three

Mission Statement: To create a wheelchair armrest able to address the needs of a stroke or TBI patient with a focus on comfort, prevention of further injury, and usefulness in rehabilitation.

Project Deliverables:

- A working prototype of the armrest and CAD model detailing each part.
- Documentation for each design choice including the rationale behind each decision.

Constraints

- Must be built with a budget of 100 dollars
- Must be fully functional for patients of all sizes

Users/Stakeholders

- TBI patients at the Shirley Ryan Abilitylab
- Stroke patients at the Shirley Ryan Abilitylab

Table 1. Requirements and specifications for the Adjust-a-ball Armrest.

Requirements	**Specifications**
Secure Attachment ● Attaches easily onto the wheelchair frame, simple and quick, a one person job ● Can quickly be moved out of the way to allow for transfers	● Can be installed in less than 10 seconds ● Can be moved out of the way in under 10 seconds

• Stays secure on the wheelchair when in use	• Holds 75 pounds of weight without breaking, tilting, or coming loose from the wheelchair
Rehabilitation • Rotates laterally • Tilt backwards with the patient, or stays in position when patient tilts backwards • Must support elbow enough to prevent shoulder subluxation	• Holds the patient's arm laterally outward at a 90° angle • Holds the patient's arm vertically at a 30° angle
Other Considerations • Provides comfort to the patient's arm and shoulder • Fits all patients • Can be cleaned easily	• Is at least 5 inches wide and 21 inches long • Is not made of porous material • Can be easily cleaned by a bleach cloth

APPENDIX B: BACKGROUND RESEARCH SUMMARY

After meeting with the client and gaining a better understanding of the problem at hand, we utilized the library resources to research more specific questions about the topic. Each member of the team explored multiple aspects of the problem rather than dividing up topics in order to obtain a better breadth of sources. Much of our research centered around the topics of stroke, TBI (traumatic brain injury), wheelchair specifications, methods of rehabilitation, and competitive and model products.

Stroke - Background and Causes

Our research led to the following findings on strokes and stroke survivors:

A stroke is the rapid death of brain cells caused by lack of proper blood circulation in the brain. The damage done to the brain cells leads to loss of motor control and cognitive function. People who have a stroke often experience paralysis or weakness on one side of their body, shoulder pain, and hypotonia ("Upper Limb Management After Stroke Fact Sheet"). In fact, more than 60% of these patients have difficulty moving around without assistance. These symptoms can lead to an unstable posture, increasing the risk of more injuries (Choi 1).

Furthermore, the difficulties that patients face are often augmented when performing daily tasks. For example, muscle strength is crucial for being able to complete daily activities, but the patient may face frequent exhaustion due to a lack of exercise and movement. When conducting research to identify issues in daily activities performed by stroke survivors in wheelchairs, we discovered that self-care was often a bigger issue than productivity. The most common self-care issues reported by both caregivers and patients were dressing and bathing (Reid 273-286).

Traumatic Brain Injury - Background and Causes

We also conducted research on traumatic brain injury patients:

We found that patients most often face problems with balance, coordination and movement. However, stroke patients tend to have a higher chance of having severe arm weakness than TBI patients. The estimated timeline for recovery from severe arm weakness is around two months

(Katz 488). On average, it usually takes patients up to six months to recover from most physical injuries caused by a traumatic brain injury. After the six-month period, patients begin to take therapy and start rehabilitation to regain their bodily functions (Kaufman 519-535).

One of the most frequent physical injuries that TBI patients experience is a lack of shoulder integrity. This injury can most often be attributed to decreased strength, paralysis, decreased muscle control, abnormal muscle tone, and postures that continually pull on the patient's humerus (Lange).

Wheelchairs

A brief description:

Originating a early as 525 CE, wheelchairs have been used throughout the world to improve the mobility of people who have difficulty walking. Most wheelchairs consist of a seat elevated on four wheels -- two large back wheels and two small front wheels. The frame of the device is usually made of metal tubing, either steel or aluminum. Modern wheelchairs allow the user to turn the rear wheels by hand and some are able to fold up for ease of storage. Motorized electric wheelchairs are available for people with significantly reduced mobility. Most manually manipulated wheelchairs can cost between 200 and 1000 dollars. (Bastos-Filho 6-10)

Though there is no standard size for a wheelchair, however, the dimensions for a manually manipulated wheelchair generally fall within (Bastos-Filho 7-8):

- Between 600 mm and 660 mm in diameter for back wheels
- Between 76 mm and 203 mm in diameter for front wheels
- 610-760 mm wide and 1100-1500 mm long

Types of Cushions on Wheelchairs

We researched different types of cushions used on wheelchairs, their benefits, and their drawbacks:

Foam cushions are made of multiple layers of foam, with the softest layer on top and the hardest on the bottom (O'Rourke 26):

- Benefits
    - Can give pressure relief with its layers of foam
    - Molds into the shape of the patient
    - Requires no inspection at all
- Drawbacks

    - Prevents patient's skin from breathing → not for patients with skin conditions
    - Used for comfort only

Gel cushions are made of gel and foam to incorporate the functions of foam cushions (O'Rourke 26):

- Benefits
    - Allows pressure relief (gel)
    - Gives a layer of hardness (foam)
    - Used for for people who can't feel where the cushion is placed and are immobile
- Drawbacks
    - Requires inspection every day
    - Freezes in places with cold temperatures

Honeycomb cushions have soft surfaces to provide comfort (O'Rourke 26):

- Benefits
    - Allows patient's skin to breathe better than foam cushions
    - Helps patients stay cool
    - Prevents pressure sores
    - Requires no inspection
- Drawbacks
    - None listed

Air cushions use air to position the patient's arm and body (O'Rourke 26):

- Benefits
    - Allows people to reposition themselves often
    - Able to move around easily
- Drawbacks
    - Requires proper inflation to function and cannot be overinflated
    - Requires inspection once a week

Sculpted cushions are often used for patients with deformities (O'Rourke 26):

- Benefits
    - Allow the patient's body to be repositioned where it is placed
- Drawbacks
    - Can't be placed around bony areas of the patient's body

Methods of Rehabilitation

Through our research, we learned about various factors that go into expediting or facilitating the rehabilitation process (Lange):

- Exercising the arm muscles on a regular basis is crucial for the patient to have the muscle strength needed to perform daily tasks
- Comfort affects rehabilitation; constant discomfort may become painful and inadvertently exhaust the patient
- Incorrect postures are detrimental to the rehabilitation process and often caused by imbalanced positioning of the body that worsen when not corrected. Without proper posture patients may go through shoulder protraction, where the shoulders are rounded forward
- Strapping down the arm is one method that is sometimes required to prevent the client from injuring the elbow joint

Competitive and Model Products

We researched various model products to understand the benefits and drawbacks of the different solutions available on the market today: the wheelchair posture support device, the adjustable armrest, and the padded wheelchair armrest with rotating base.

Wheelchair posture support device (WPSD) (Veneman 525-534):

- Benefits
    - Ensures that the patient has the correct posture so that they no longer need to spend time correcting it
    - Reduces the pain the patient experiences when repositioning themselves
- Drawbacks
    - Looks like it is “containing” the patient in the chair

Adjustable armrest (Smith 53):

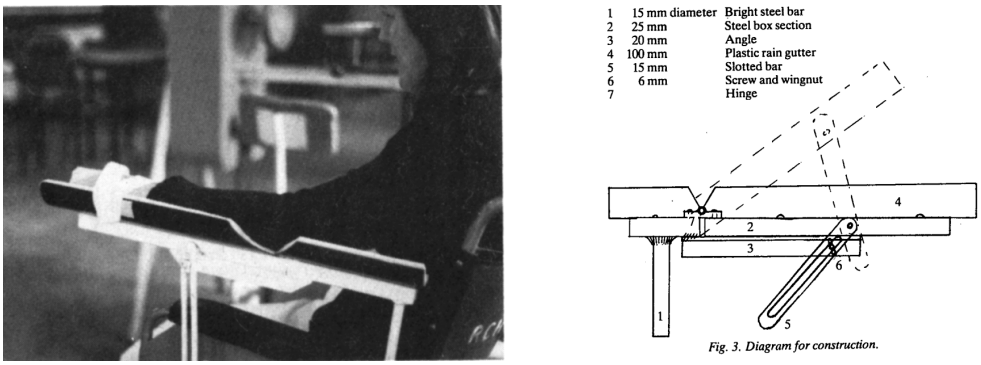

Image A. A real-life example of an adjustable armrest (left) and a diagram showing its material construction (right).

- Benefits

    - Can be adjusted by height
    - Can be adjusted by angle of the arm
    - Allows the patient's arm to sit at a 90°
    - Extends the elbow
- Drawbacks
    - May become flimsy over time through constant use

Padded wheelchair Armrest with rotating base (Reizen):

Image B. A real-life example of an armrest with a rotating base

- Benefits
    - Can swivel
    - Is held by a trough-like pad and a strap
    - Can be placed in multiple positions
    - Supports the patient's arm well

- Drawbacks
    - May not provide sufficient lateral support due to small pad size
    - Contains moving parts that may break
    - May be too tall for comfortable arm positioning

APPENDIX C: CLIENT INTERVIEW SUMMARY

On Wednesday, October 2nd, 2019 at 5:00 p.m., in the Ford Motor Company Engineering Design Center, we had our first interview with Courtney Celian, an occupational therapist from the Shirley Ryan Abilitylab. We conducted this interview in order to better understand the problem with current wheelchair armrests and to gain insight into the users' conditions and the rehabilitation process. This memo summarizes the meeting and what we have learned about current armrests, the effects of brain injuries, and ideal armrest features.

Users

Our client answered questions about the user demographic:

- Many of the wheelchair and armrest users in the Abilitylab are people with a traumatic brain injury or have had a stroke.
- Most are gentlemen between forty and sixty years old who have been injured in a fall, though patients of all ages, shapes, sizes, and genders are treated there.

Conditions

Our client detailed the effects of stroke and TBI on the upper extremities. Patients may:

- Neglect one side of their body after the injury, which could cause injury if the unused side of the body is not properly secured in the arm rest.
- Experience hypotonia, when the arm muscles remain completely relaxed, or hypertonia, when the patient's biceps cause their arm to curl in towards their chest.
    - Typically, the muscle tone in patients' arms progress from hypotonia to hypertonia over time.

If the affected arm is not properly positioned in the armrest, ramifications include:

- Shoulder subluxation, when their shoulder is disconnected from its joint by the weight of their neglected arm and muscle weakness.
- Arm tendons decreasing in length, which will require surgery to lengthen the tendon.
- Postural deformities.

Types of Armrests

Our client described the three types of armrests currently in use at the Abilitylab, listing their advantages and drawbacks:

Slide-On Arm Trough
Advantages:

- Easy to slide on and off.

Drawbacks:

- It is often too far to the side from smaller patients' bodies, forcing them to lean over to keep their arm on the trough.
    - May lead to postural deformities.
- It is not secured well to the wheelchair; the weight of the patient's arm causes it to tilt.

Screw-On Armrest
Advantages:

- None reported

Drawbacks:

- It loosens from the wheelchair very easily, as the screws often strip and come off.
- The armrest must be entirely removed from the wheelchair during transfers.
- It is difficult to fix and must be sent to the experts in the wheelchair room for repair.

Half Lap Tray
Advantages:

- The lap tray provides a large surface for the arm to rest on.
- Easy to slide on and off.
- Can be flipped upwards to move out of the way.

Drawbacks:

- The tray does not remain level and falls off easily, especially under the weight of a larger patient's arm.

Implications for Requirements

Our client listed features she would like to see in a "dream armrest":

Attach easily:

- Connected securely to the wheelchair frame without any unwanted roll or tilt.
- Easily slide off the wheelchair when necessary.

Accommodate all:

- The armrest should be able to fit each patient's arm size and shape in order for their elbow to be below their shoulder
- The armrest should be comfortable for the patient

Rehabilitate:

- Able to rotate laterally in order to stretch the arm and chest muscles.
- It should tilt backwards when the patient does, not allowing the elbow to slip back, but it should also be able to stay in place if needed.
    - Tilting backwards takes pressure off the patient's back.

Easy to clean:

- Can be wiped down by a bleach cloth
- Not made of porous material

Conclusion

This interview allowed us to further understand the requirements and specifications of the client. When we conduct our user observation next week, we will take measurements and observe how patients interact with the armrests as well as record the details of the wheelchairs used at the Abilitylab.

APPENDIX D: USER OBSERVATION SUMMARY

Alec Greenwald and Peter Tuchler visited the Shirley Ryan AbilityLab in Chicago and met with their client, Courtney Celian, on Monday, October 6, 2019. The visit had two purposes: First, a trip to the "Wheelchair Room" to talk with a technician about the wheelchairs used at the AbilityLab as well as hear his expert opinion on the various armrests used by the facility. Second, a meeting with the patient, where we had the opportunity to observe her as she interacted with a wheelchair and to ask her questions about her experience. The purpose of the visit was to gain a better understanding of how the user performs daily tasks with her current armrest and to further explore the equipment at the AbilityLab. The session lasted slightly over an hour. What follows explains our observation process and discusses our findings.

Methodology

The observation took place at the Shirley Ryan AbilityLab, a facility that specializes in the rehabilitation of patients with traumatic brain injury, spinal cord injury, stroke, and other conditions. The user was interviewed in the tenth-floor main lobby for about 30 minutes to gain information about her and her thoughts on the current armrests. We watched her operate the wheelchair and demonstrate the range of motion of her affected arm, and we took notes as she described her ideal armrest. During the visit to the "Wheelchair Room" we interviewed the technician about his thoughts on the benefits and drawbacks of the current armrest technology. We asked both the user and the technician if they had any preferences and ideas we should keep in mind.

Information About the User

The user is a young woman in the middle of her recovery process at the AbilityLab. Her current symptoms include hypotonia (lack of muscle tone) in her left arm and shoulder. She is experiencing shoulder subluxation on her left side as a result of the hypotonia, and this is causing pain in her left shoulder. To mitigate this pain, she prefers to keep her affected arm on a pillow across her lap instead of on the wheelchair armrest. The user has regained a bit of motion in her left arm and is able to shrug her left shoulder up about an inch before feeling pain. She has the ability to walk with assistance.

User's Difficulties with Armrest

- The armrest is not secured well to the wheelchair and rolls to the side when an arm is in it
    - When her arm slips out of the rest, it pinches her arm between her body and the armrest
- The walls of the arm trough are not high enough to hold her arm in, especially when the armrest tilts to the side
- It is uncomfortable because it positions the arm in an awkward way

The user decided to use a pillow instead of the armrest:

- Benefits:
    - More secure and comfortable than the armrest
    - Easy to put on and remove
- Drawbacks:
    - Does not provide enough elbow support
    - Requires frequent adjustment

User's Ideal Armrest

The ideal Armrest will satisfy the following requirements:

- Comfort
    - It will be well padded
- Stability
    - Securely attaches to the wheelchair
    - Provides sufficient elbow support
    - Includes a strap to keep the arm in place
- Therapeutic functionality
    - Can pivot horizontally about the elbow to allow for stretching
    - Has the built-in ability to aid in resistive training to boost muscle tone

Priorities of an Improved Design

- Create comfort
- Allow for easy use
- Establish stability
- Allow for elbow support

Information about the Wheelchairs and Armrests found at the AbilityLab

We were able to examine the wheelchairs and armrests in person. Below are our findings:

Slide-over armrests (they slide over the existing smaller armrest)

- Benefits:
    - Easy to put on and remove quickly
- Drawbacks:
    - They are loose and break easily
    - Current models allow for minimal adjustment

Screw-on armrests: (they screw directly to the wheelchair frame)

- Benefits:
    - They are more secure than slide-over armrests
- Drawbacks:
    - If not used properly, or if subjected to a large amount of weight, the screws will strip or bend
    - They are difficult to put on and remove

C-clamp armrests: (attached to the wheelchair frame by pressure)

- Benefits:
    - Allows for a more secure way to attach armrest (of those at the AbilityLab)
    - Relatively easy and quick to put on and remove
- Drawbacks:
    - The C-clamp mechanism, especially those with the quick release, are prone to user-error and are difficult to fix.

The technician provided some suggestions for the armrest:
Ease of Use Suggestions:

- Make it “idiot proof” so that patient’s families do not accidentally break it during use

Stability Suggestions:

- Attach it to the frame using a C-clamp or similar
- Mount it to the back cane, not the armrest frame, making it easier to move out of the way
- Avoid a bulky pivot mechanism -- it can make the user’s arm sit too high

Notes on wheelchair standards:

- Not all wheelchairs are the same size or have the same dimensions. Further, not all armrests are the same size (see Image A). This means our design must fit a variety of

molds and be able to mount to various sizes of tubing, regardless of where the holes are drilled.

Image A. The armrests in the Abilitylab are not always the same size, as shown in the image above.

User/Wheelchair Room Observation Table

Table 2 lists the observations, opportunities these created for our design, the follow-up to these opportunities and suggestions the user or the technician had.

Table 2: Observations, opportunities, follow-ups, and user suggestions obtained from the user observation.

Observations	Opportunities	Follow-Up	User Suggestions
The user's arm does not stay stationary on the armrest	Provide a way to make her arm stay in place	Add high friction materials	Over-arm straps
Current armrests are bulky(See image A below)	Create something sleek	Use better-cushioning materials that are less spacious	
Current armrests are not stable	Make a clamping mechanism that maintains stability	Use the bars in the back of the wheelchair	Use a C-clamp
User can have difficulty with	Make it easy to use	Simple clips	

adjustment			
Armrests must be moved out of the way for transfers	Attach it elsewhere on the frame	Metal bars in rear	Connect it to the back cane so that it can pivot out of the way
People come in all shapes and sizes	Make it adjustable	Adjustable length and width	Multiple sets of attachment holes
Needs to be mobile for stretching	Create multiple axes of motion	Ball and socket joint	

APPENDIX E: USER TESTING RESULTS

Purpose

The purpose of our user testing was to offer three different armrest solutions to our stroke patient to determine which features were either favorable or not favorable. We would use the feedback given by our user for building future armrest prototypes: one with a ball and socket joint, another with a rotating armrest on a sliding track, and a third with alligator teeth rotation and height change pin. Our goals were to learn two things: (1) which form of joint proved to be the most purposeful and easy to use for the therapist, and (2) which mechanism was best suited to provide the utmost comfort for our users.

Methodology

The user testing was performed with three mockups, each with a distinctive mechanism: the ball-socket mechanism, the rotating armrest on a sliding track mechanism, and the alligator-teeth rotation and height change pin mechanism. The first mockup uses a ball socket attached to the back end of the armrest piece, which allows the armrest to rotate in direction at any angle when the screw is loosened. The second is designed to rotate the armrest up to 90 degrees to the right on a curved track and to tilt the armrest upward up to 30 degrees through a lounge chair and pin mechanism. The last mockup combines an alligator teeth rotation mechanism, which allows for horizontal movement in 30 degrees increments, with a height change pin mechanism that utilizes two poles that move up or down, both individually and simultaneously.

The overall testing procedure was sectioned into four parts and aimed at determining the comfort level of each armrest position based on what the patient sitting in the wheelchair says. Each mockup was attached onto the bare armrest tube found on the wheelchairs of our client's patients. We then tested the comfort levels of four different positions on a 1 to 10 scale:

- An elevated position
- 30 degrees upward
- 30 degrees downward
- 30 degrees outward

Results

Before analyzing the results of our user testing, it is important to note that the stroke patient we were working with had to leave early, so the feedback she was able to provide was limited, and our group was not able to present all of our mockups to the user. Thus, we turned to Courtney Celian, our client, for her insight on our armrest mockups, and our results are partially based on her feedback.

Table 3 summarizes the user testing results. In the ratings, 1 is most comfortable for the user, 10 is least comfortable for the user.

Table 3: Testing results as rated by the user.

	Elevated	30° upward	30° downward	30° outward	Comments
Ball-socket	N/A	1	2	1	Best comfort, but cannot hold over 8 lbs
Rotating armrest on a sliding track	N/A	1	N/A	7	Most sturdy design, least functionality and extreme discomfort for 30° outward
Alligator teeth rotation with height change pin	6	3	4	2	Prone to breaking, most functionality but very bulky

Ball-Socket Mechanism

Although the ball and socket mechanism had a very wide range of motion, it's lack of stability was a major drawback in its design philosophy. Thus, in our future design for this mockup, we would look into a ball of a larger size, which would be able to support more weight and hopefully eliminate the issue of stability.

- Advantages
    - Very simple to use due to its single knob for adjustment
    - Had the greatest range of motion out of all three designs
    - Most comfortable due to the pivot point staying in place

- Disadvantages
    - Could only hold up to 8 lbs of force due to the small size of the ball and socket
    - Tip of the armrest is not well supported due to the mockup having only one supporting beam

Rotating Armrest on a Sliding Track

The rotating armrest on a sliding track mechanism was very well received by our client, mostly due to its sturdiness, having a mechanism that flips the armrest out of the way when needed, and its ability to swivel outward as well for an even wider range of motion. The main drawback in its design philosophy was the size and weight of the mockup, which was necessary to fit all of these features into the armrest. Thus, in our future design for this mockup, we would look for a sturdy but lightweight and thin material, most likely some form of metal, to reduce the weight and size of the armrest.

- Advantages
    - Extremely sturdy due to the mockup having two supporting beams at all times
    - Can flip 90° outward due to hinge on the outer side of the armrest
    - Decent range of motion both vertically and horizontally
- Disadvantages
    - Slightly bulky, causing the whole armrest to sag when placed on the wheelchair
    - Extreme discomfort when rotating to 30° outward due to the nature of sliding mechanism

Alligator Teeth Rotation with Height Change Pin Mechanism

The alligator teeth rotation with the height change pin mockup was a combination of two different designs created by our team. One mechanism that differentiates this mockup from the rest is its ability to elevate the armrest as a whole. However, our client did mention that this feature would not be commonly used, for it may cause discomfort to the patient. The alligator teeth rotation with height change pin mechanism was definitely bulkier and more unstable than what was desired, so that caused several problems during the user testing, including the armrest physically breaking apart. The idea of the mechanism itself was still well-received, so for our future design, we would focus on utilizing stronger materials and slimming down the design itself.

- Advantages
    - Able to lift the whole armrest up to a higher position
    - Can adjust to lots of different positions that the other two armrests cannot achieve

- Disadvantages
    - Most bulky design out of the three mockups
    - The aforementioned features are not very useful for our client or the user
    - Extremely fragile and unstable design
    - Slightly difficult to adjust using the height change pin mechanism

Analysis, Conclusions, and Limitations

From the observations made from the user testing, the following can be concluded:

- The ball and socket mechanism was well-received for its wide range of mobility in any direction from a single pivot point. The main drawback with this design was its inability to hold more than 8 pounds, which would not be enough to support the patient's arm on a daily basis.
- The rotating armrest on a sliding track mechanism was well-received for its extreme stability and multi-functionality. The main drawback with this design was the massive size and weight of the design, which resulted from the wood material used to create this mockup.
- The alligator teeth rotation with height change pin mechanism was well-received for its fairly simple functionality, as well as its wide range of vertical mobility. The main drawback with this design was its fragility and unstableness, which stemmed from choice of material and use of hot glue to attach most parts together.

When comparing all three mockups, several key observations were made. In terms of range of motion, the ball and socket mechanism was most favorable because of its near-infinite mobility, both vertically and horizontally. However, its inability to hold a lot of weight was a huge problem, and if our group decides to move forward with this design, the weight issue would be something we must solve, possibly with a larger ball and socket mechanism. Meanwhile, the rotating armrest on a sliding track was the most stable because of its two points of contact for its vertical motion mechanism. The horizontal mechanism was also stable and functional, but the user did find it uncomfortable when the armrest was in an outward position. Finally, the only prototype that could raise the armrest as a whole was the alligator teeth rotation with height change pin mechanism. However, this functionality was deemed unimportant by the client. Though the functionality overall was good, this mockup was highly unstable and prone to break.

Due to time constraints during our user testing specifically, we did not have time to ask the patient any of our questions. As mentioned previously, the feedback we received for our mockups from the user was limited, and we had to turn to our client, Courtney Celian, to finish our testing.

Regardless, more mockups should be made based on the results of these tests, and should be tested again to ensure the design's comfortability and mobility.

APPENDIX F: PERFORMANCE TESTING RESULTS

Purpose

Our objective was to collect data on the structural integrity of the ball and socket mechanism that we incorporated into our design.

Our goals are to learn:

1. The amount of force that can be applied against the mechanism in each direction without any slipping.
2. What is the best way to incorporate our mechanism in our final design so that the armrest is mounted the most securely.

Methodology

In order to collect concrete data on the strength of the mechanism, we performed a series of tests that apply force to the end of the armrest in various directions. We mounted our armrest on the end of a piece of 1-inch-diameter aluminum rod that was clamped in a table vice. We applied downward force using weights placed at the end of a piece of 3/8th inch plywood (with the same dimensions as the base of our arm-trough) when the armrest was in both forward position and rotated 90 degrees to the side. We also applied force on the armrest in the direction of horizontal rotation, however we were not able to measure this force quantitatively during testing and instead recorded our observations.

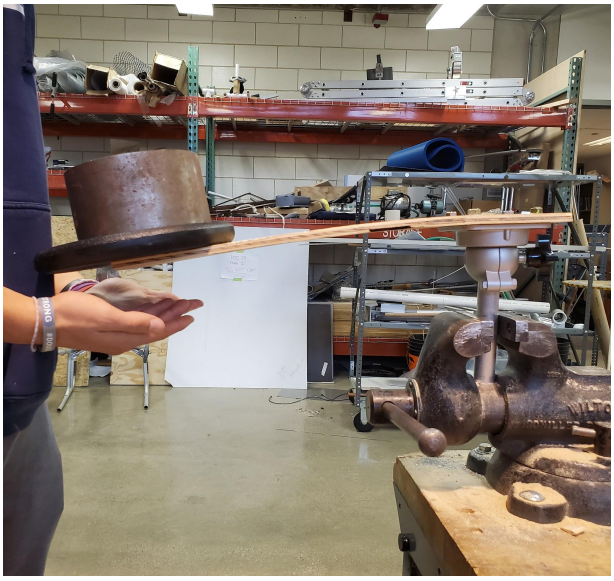

Image A. Testing how much weight the mechanism can hold.

Results

Forward position:

The mechanism held 40 pounds* at a distance of 17 inches from the pivot with no slipping (See Image A, left)

- Note: The plywood bent significantly, but the mechanism did not move at all.

Side position:

The mechanism held 40 pounds* at a distance of 17 inches from the pivot with no slipping. (See Image A, right)

- Note: The plywood bent significantly, but the mechanism did not move at all.

Force in the direction of horizontal rotation:

We we did not detect any horizontal rotation in the mechanism when we applied force to it. We did, however, notice slipping on the interface between the mechanism and the aluminum rod when using a lot of force. This can perhaps be attributed to the diameter of the rod being slightly too small.

*40 pounds is not the point of failure of the mechanism, it is simply that we did not feel comfortable adding more weight because the plywood may break. In fact, we believe the mechanism can support more than that, as it is rated to 75 pounds.

APPENDIX G: DESIGN REVIEW

Summary

We began our design review by going over what we thought were the most important requirements for our armrest prototype. First, the requirements given by the client and users were reviewed. From these inputs, we gathered that the most important requirements for us were secure and easy to use attachment, functionalities that would assist in rehabilitation, and comfort.

We then went over our previous mockup designs: the alligator teeth rotation with the height change pin, the rotating armrest on a sliding track, and the ball and socket joint. Ultimately, we felt that the ball and socket mechanism would work best for the next iteration of our armrest prototype due to its superior range of motion, intuitive method for adjustment, preferable elbow positioning, and lightweight design.

For our newest prototype, we used a PanaVise 400, a ball and socket vice originally meant for wood carving. The diameter of the ball used in the PanaVise 400 is more than twice that of our previous ball and socket design, giving our design much more stability. Another bonus was that the mechanism itself is only 1.5 pounds, and it can hold up to 75 pounds when the armrest is 45 degree angle.

After presenting our design to our DTC cohort, we received constructive feedback, which is organized in the table below.

Table 4: Feedback from peers and professors.

Reviewers like	Reviewers dislike	Features to be added	Features to be removed/modified	Additional comments
Adjustability The wide range of vertical and horizontal motion offered by the ball and socket design	**Switchability** The current design can only work with the right side of the wheelchair due	**Cushioning** A layered cushion on the armrest may better accommodate for people of varying sizes and weight.	**Armrest material** Switch over to a leather-like material instead of the plastic cover that is seen	**Presentation** The requirements part of the presentation should have

Simplicity The design is minimalistic and easy to understand but still very effective in fulfilling the rehabilitation requirements	to the adjustment knob **Armrest size** The armrest trough is too narrow, and heavier patients would not be able to have their arms be properly supported by the bottom **Back part of armrest** The C-shaped section in the back of the armrest would hit the wheelchair when tilted up	More similar to that found in pillows. **Specifications** We need more quantitative data regarding our armrest, like maximum weight that our prototype can support **Strength of armrest** The patient should be able to push off of the armrest without it moving or sagging due to the weight	in our current design **Attachment** The tube should not be able to rotate when locked in place	been more concise We should have focused more on the latest prototype The demonstrator and speaker should have presented side-by-side

APPENDIX H: DESIGN FREEZE DOCUMENTATION

Design Description

Our team aims to design a comfortable and multi-functional armrest for a wheelchair using a ball and socket joint to create a mobile tool for the physical therapy of stroke patients with hypertonia in their upper arms. Our armrest design helps stretch the muscles of the shoulder and below by being able to angle the arm upwards, rotate the armrest orbitally while keeping the patient's elbow fixed in place, and maintain the comfort of the patient.

Our design utilizes a ball and socket joint that rotates from the base position both 90 degrees upward and 90 degrees horizontally either toward or away from the patient. This feature is included because it provided the most axes for motion and in turn the most motions needed for physical therapy. The mechanism is fixed by screwing in a knob as tightly as possible into the joint and the rest is then held at the chosen location (Image B).

Another key feature of our design is the way in which it is connected to the wheelchair. It is mounted via three-cushion u-bolts connected to a metal plate on one side with a short piece of one-inch diameter aluminum rod on the other side. Multiple cushion u-bolts tighten onto the existing frame of the chair fixing it in place with multiple clamps being used for security. The rubber cushion of the u-bolt helps to mitigate rotational slippage from torque on the armrest created by the patient.

The final component of our design is the arm trough. In our design, we decided to build a flat bottom trough so it is comfortable for both smaller and larger arms. It is asymmetrical with the side closer to the body lower than the outer side so it does not dig into the arm.

Image A. The arm-trough is asymmetrical to allow the patient's arm to rest comfortably in the armrest.

This allows the elbow to stay comfortably close to the user's side, helping with posture. The arm-trough is finished in treated polyester fabric, a material that is comfortable, durable, affordable, and easy to clean.

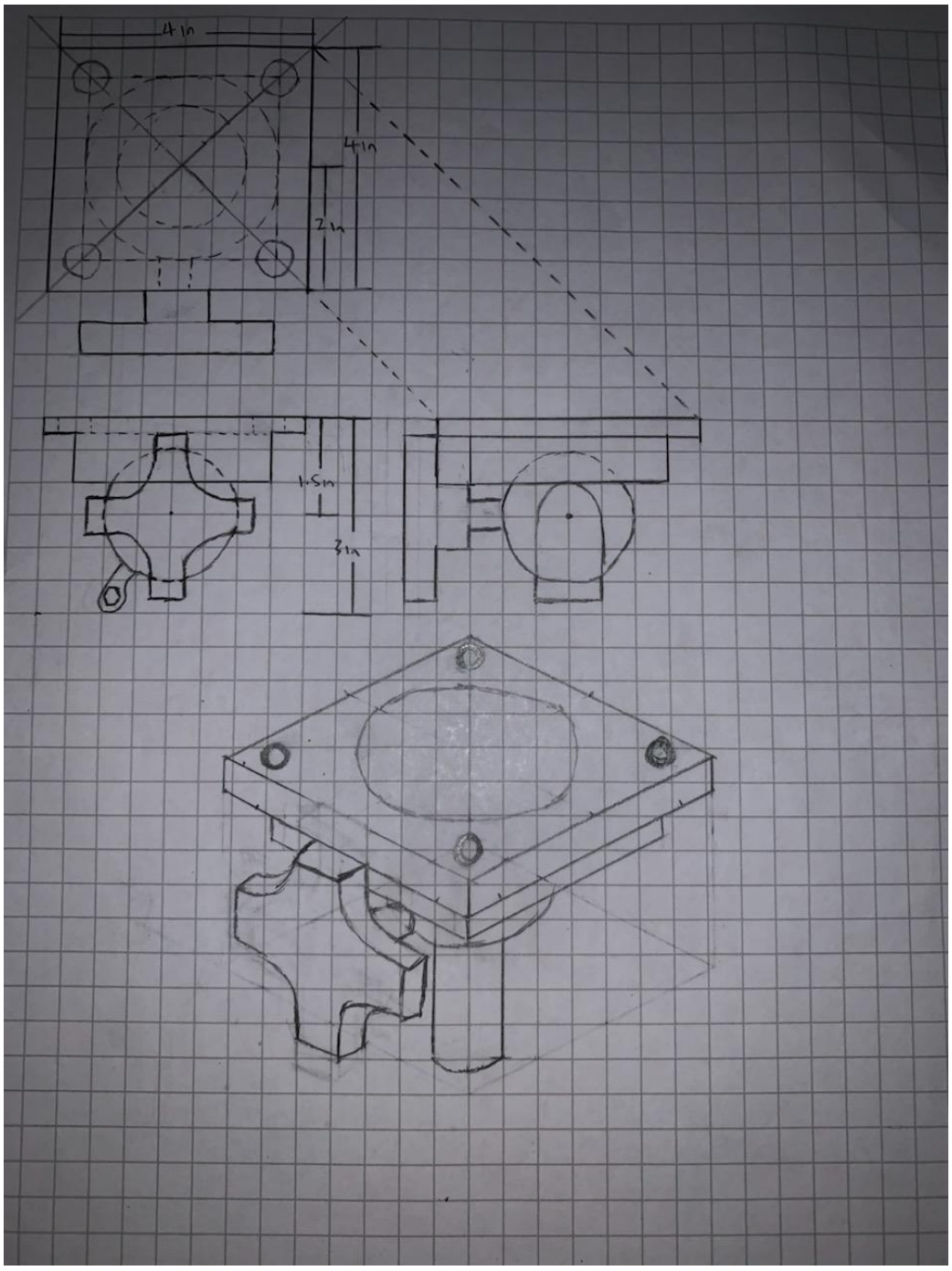

Image B. Orthographic and isometric drawings
of the ball and socket mechanism.

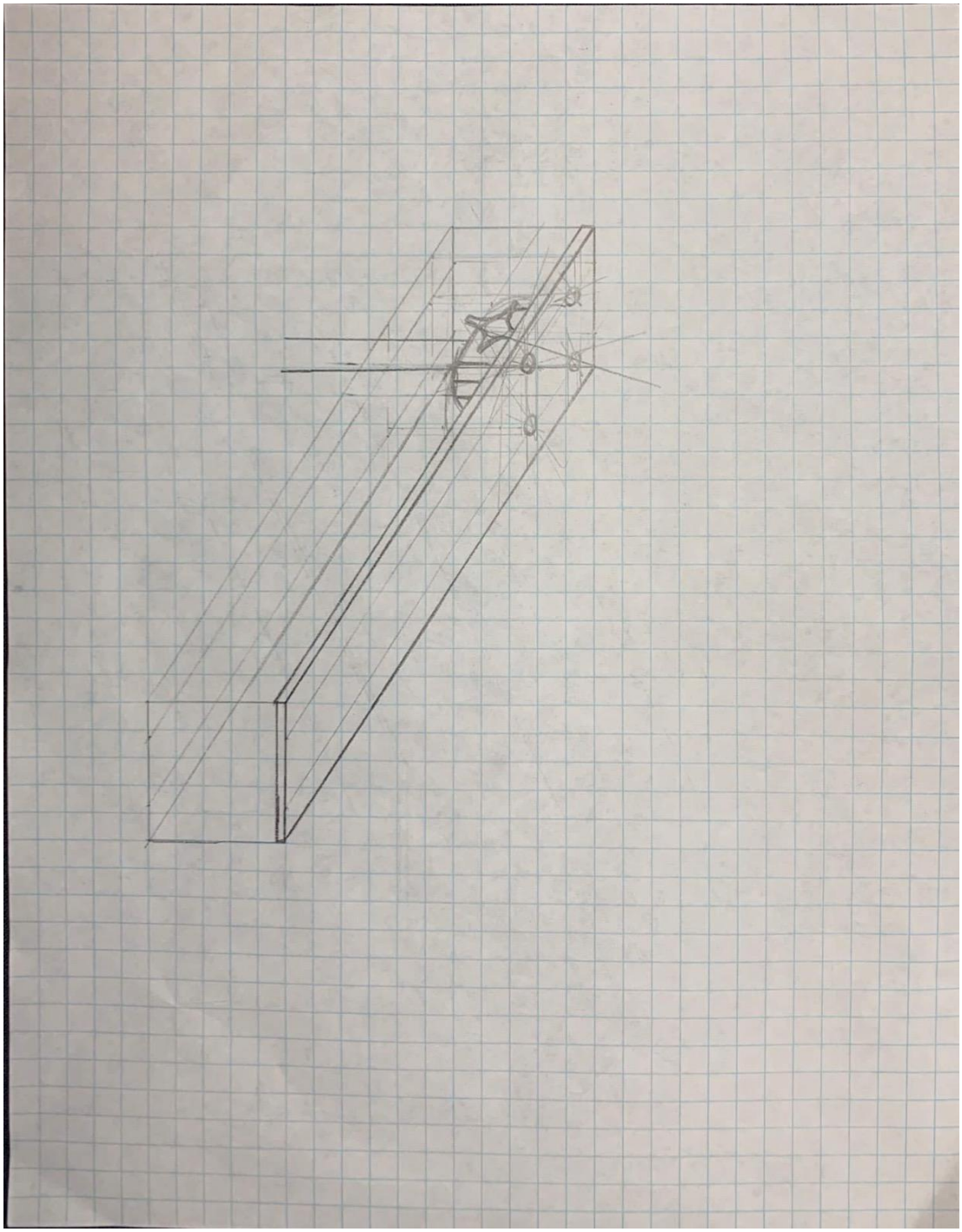

Image C. Isometric drawing of the Adjust-a-ball Armrest.

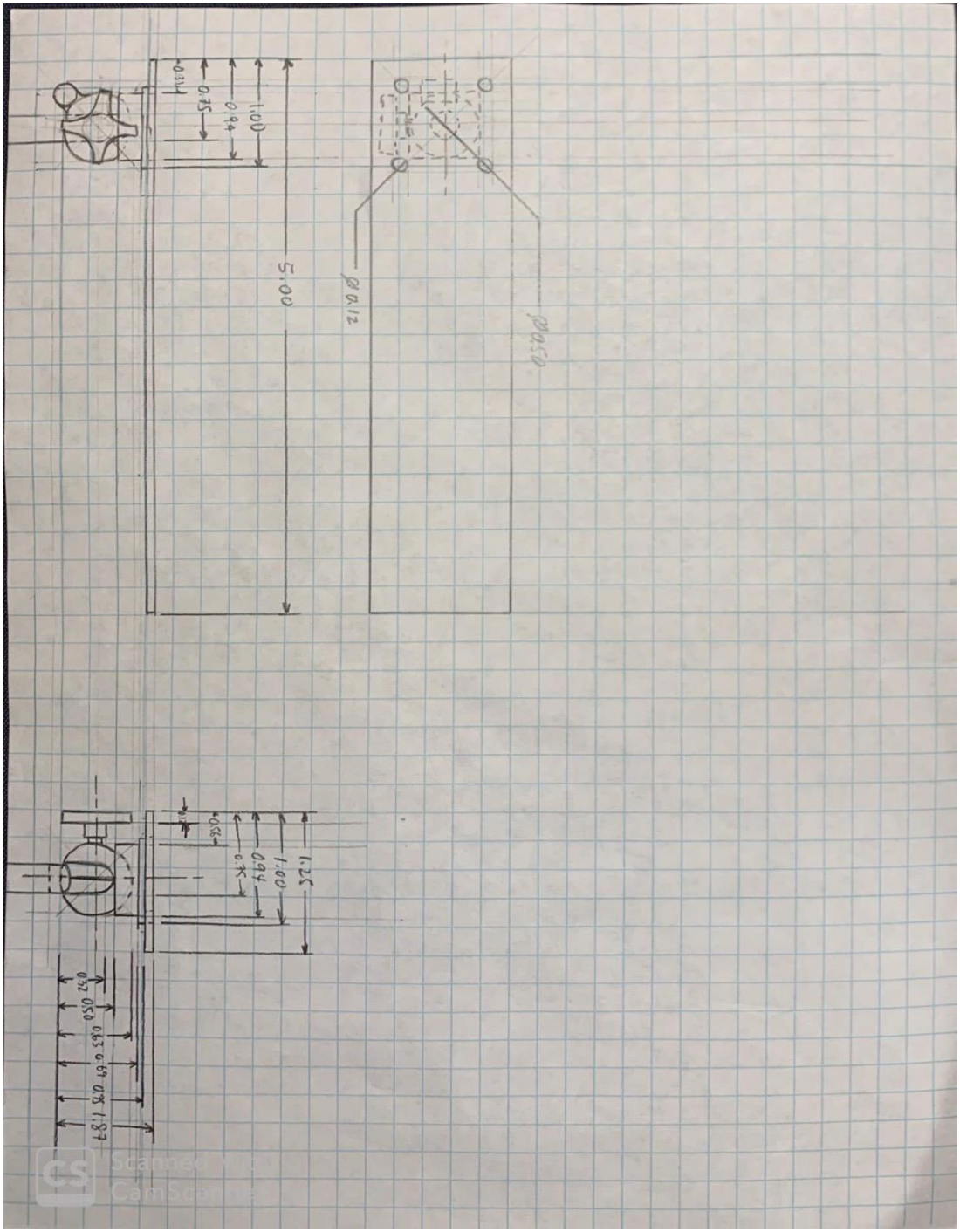

Image D. Orthographic drawing of the Adjust-a-ball Armrest.

APPENDIX I: BILL OF MATERIALS

Item	Description	Qty	Vendor	Part Number	Unit Cost	Total Cost
PanaVise Model 400 Heavy Duty Base	Accepts any 1” (25.4mm) diameter shaft. Recent engineering changes all the 400 base to hold up to 75lbs (34.0kg) at 45 degrees • Height: 3.25” (82.5mm) • Weight: 1.5 lbs (0.7kg)	1	Amazon	400	$40.49	$40.49
Zinc Yellow-Chromate Plated Hex Head Screw	Head: Width:5/16” Height: 1/8” Body Length:1.25” Thread: 10-24	1	McMaster-Carr	92620A202	Per 5 pack: $10.35	$10.35
18-8 Stainless Steel Hex Nut	Thread: 10-24 Width:⅜” Height: ⅛”	1	McMaster-Carr	91841A011	$3.77 per pack of 100	$3.77
BLACK ACETAL SHEET	0.030" X 12" X 24"	1	ePlastics	ACTLBLK0.030X12X24	$10.36	$10.36