Final Design Report: The Triple Elbow

Prepared For:

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Executive Summary

Adolescents with spinal cord injuries that results in play video games as a form of therapy at the Shirley Ryan AbilityLab in Chicago, Illinois. The goal of this therapy is to strengthen the muscles in the shoulders and faces of patients as well as to promote independence in the individual. Therapist Jordan Huffman has expressed a need for a new way of setting up an adaptive video game design, considering the current system involves limited adjustability, unstable objects and unnecessary therapist involvement.

The purpose of designing a new adaptive video game system is to increase the range of positioning of buttons to accommodate a variety of users. In addition, the new system allows for more patient independence by creating a stable base and button-holding device that will minimize the work the therapist is required to do to maintain button position.

The process used to develop the design involved the creation of multiple mockups, the testing of those mockups, and an initial prototype. This prototype was tested and modified to become our final prototype: The Triple Elbow.

The improved design, the Triple Elbow, is a stand-alone device that allows a therapist to position adaptive gaming controls around the face and shoulders of a patient quickly and easily. It holds up to four adaptive gaming controls on four articulating arms that are able to reach the correct points around the patient.

The Triple Elbow consists of the following features:

Base	Set apart from the actual wheelchair. Makes it easier for the therapist to set up and take down as it requires no detaching from the wheelchair.
Vertical aluminum extrusion	Allows for vertical height adjustment of the rotational arms to fit an individual of any height.
Rotational Arms	Maximizes the range of positions a button is desired to be in with spherical joints that can be moved in any direction
Button holders	Stabilize the buttons by clamping them

	between metal and tightening with a wingnut.

Table 1: Features of the Triple Elbow

Introduction

Spinal cord injuries occur with various levels of severity and are classified by the location of the damage. Our client works with patients who have sustained injuries to the top four vertebrae of the neck. This sort of damage is the most severe type of spinal cord injury and typically results in loss of function of legs and arms and affects movement in the stomach and chest.

One way that spinal cord injury patients work to strengthen their already limited movement is through video game therapy. Adaptive gaming involves a system of buttons that can be activated by the shoulders, head, and facial features of the patient; each button corresponds to a control in the game.

Our team was asked to design a solution to a problem with the adaptive gaming setup at the Shirley Ryan Ability Lab: the controls for a gaming therapy session do not stay in place and often must be held by the therapist. Controls must be taped directly to a patient's wheelchair and the force required to activate them can push them out of reach of the patient. The setup also requires the therapist to entirely dismantle the setup at the end of the session, meaning they also have to set it up all over again for the next patient.

The Triple Elbow solves these problems by providing a stand-alone device that holds up to four adaptive gaming controls on four articulating arms that fold in or extend fully to position these controls around the face and shoulders. It also adjusts vertically to allow for quick adaptability between patients and gaming sessions.

The purpose of this report is to describe in detail the process in which the Triple Elbow was designed, an illustration of the final product including how it was constructed and directions for use, and the reasoning behind the final design. Further sections include the requirements of the design and a description of the users, the concept of design as well as the rationale behind it, and next steps for the design.

Users and Requirements

Main Users of the Design

Jordan Huffman, project partner: Ms. Huffman is a therapist in the spinal cord injury department at the Shirley Ryan AbilityLab. She is in charge of setting up the adaptive gaming device and supervising during gaming sessions.

Individuals with Quadriplegia: One of our main users are patients at the Shirley Ryan AbilityLab between the ages of 10 and 20 who have spinal cord injuries, meaning they only have use of their shoulders, head, and facial features. These patients use adaptive video gaming as both a source of entertainment and a form of physical therapy.

Requirements for the Design

Adjusts quickly between a variety of users:
Due to the range of ages of patients in the spinal cord injury department, it is essential that the device be able to accommodate a number of buttons in locations desired by the patient and/or therapist (see Appendix B). Both the number of buttons and placement of the buttons should be able to change based on user size and user preference. In order to achieve this, the final product has been designed to be able to position at least four buttons in a location reachable by the patient (see Appendix E). This tends to be within one inch of the body part that will activate any given button.

Patients can play independently, without needing readjustment from therapist:
With the current solution, the buttons constantly move with use, and require the therapist to reset them frequently and occasionally even hold in place to allow continued gameplay, making increased stability a priority. In order to promote patient independence, the therapist would like to have a minimum number of unstable parts (see Appendix B). The therapist specifically desires a standalone device in order to maximize stability during use (see Appendix D).

Easy set up and tear down:
In order to maximize the amount of time spent playing video games during therapy, the therapist desires a system that can be consistently set up in under 15 minutes and taken down in 5 minutes (see Appendix B); the current solution takes at least 15 minutes to set up and position properly (see Appendix D). Therefore, the Triple Elbow needs to be quick to set up and easy to adjust: ease of positioning is the primary goal of the Triple Elbow's design (see Appendix A).

Easy to move structure:

The therapist's strong preference for a standalone system of adjustment (see Appendix D) implies that if an independent design is presented, it must be easy to move for a wide range of users. In this case, these users are those who assist individuals with spinal cord injuries. The final project must be able to move around easily and without struggle, considering the device will likely be set up by only one person. To make our device accessible to the widest user-base, we have attached two wheels to the back-end of the base which will allow the therapist to supplement their force with that of the ground to keep the base from falling.

Design Concept and Rationale

The Triple Elbow is a freestanding system of arms extending from a post, which promote rotational adjustability for the therapist to position buttons in a variety of locations. Patients with spinal cord injuries can use this system to play video games, and therapists can easily adjust the system to fit the size of the patient and their wheelchair. This stable and fully adjustable button holder solves Shirley Ryan's current design issue of buttons falling out of place as well as the lack of rigidity in the use of velcro and tape to hold buttons in place.

The Triple Elbow consists of a base for the therapist to place behind a wheelchair,which wraps around its sides, and a channeled aluminum post extending vertically from the base. On this post are rotationally adjustable arms that the therapist can loosen to adjust, then tighten to stabilize when the buttons attached to the end reach their ideal placement. The buttons are held by a clamping case which the user can loosen to insert a button, and then tighten to hold it in place.

The base of the device supports the height adjustment and arm sub-assemblies. It also stands flat on the ground to maximize stability. The base consists of one fork spaced apart with wheels attached to the back. The therapist can move the base by pulling it back onto its two wheels, then wheeling it forward until the forks surround the patient's wheelchair, and standing the base back up so that it surrounds the back and sides of the wheelchair. Though the therapist expressed approval with a device being attached to the chair, it was stated that it would be preferred if the device was a standalone (see Appendix D). The client specified that the device needs to be stable (see Appendix B) if it is independent from the wheelchair to eliminate potential accidents. Additionally, the device needs to be as close to the wheelchair as possible to enable the full range of adjustment.

Figure 1: Triple Elbow Base

The arms have multiple joints with full rotational adjustability. The user loosens the wingnut on each joint to enable a full range of motion to change the angles of sections relative to each other. The user then tightens the wingnut on the joint once the desired position is reached in order to hold the position of the arm in place. Firmly tightening the wingnut causes the joint to bind and hold firm with use. Since adjustability is the main goal of the new design according to both the therapist and personal observation of how the patient and client interacted with the previous system(see Appendix B, D), the team decided that almost full rotation of extending arms would be an ideal way to achieve placement of a button in a large range of positions.

Figure 2: Joint allows full rotational adjustability

The placement of the arms also adjusts vertically on the base. The adjustable arms attach to a metal plate which slides up and down on bolts with heads fitted into the channel on either sides of the extruded aluminum post. To adjust the vertical position of the arms, the therapist unscrews two wingnuts--one above and one below the point where the arm attaches to the plate--and slides the bolt heads to at any height along the central post. Once the desired position is reached, the therapist then screws the wingnuts back in to hold the arm in place. The wingnut allows for quick adjustments between different-sized patients, which is an issue with the current system (see Appendix B). Considering we had the height of our smallest patient (see Appendix D) and our largest patient (see Appendix F), we used the maximum height in order to accommodate patients of all heights in their wheelchairs.

Figure 3: Height Adjustment Mechanism

The jelly buttons are held within a three-pronged triangular case that can be extended or contracted in length to insert and remove the button. The therapist unscrews a wingnut to extend the button holder, places the button into position (braced against two adjacent prongs), then tightens the wingnut again to contract secure the button in place. Based on the initial interview with client Jordan Huffman, one of the primary goals is minimizing the amount of unstable objects (see Appendix B). The response to this was a button holder that involved simply loosening and tightening a wingnut. This attachment solved the issue of unstable objects considering the triangular case is fastened directly onto the adjustable arms. Based on personal observation (see Appendix D), it was also concluded that more durable attachments needed to be used rather than the current system of velcro and/or tape. Solving this issue is another benefit of having the button secured by wingnut rather than an object that can lose its adhesion. Additionally, if not in use, a button may be easily removed and used for another patient if desired

Figure 4: Jelly-button holder

The microswitches are held by a screw that the microswitch can be directly mounted onto. The therapist places the hole on the back of the microswitch over the screw and spins the switch onto the screw until it is tightly secured. As with the Jelly Button Holder, one of the primary goals for the triple elbow is minimizing the amount of unstable objects (see Appendix B). Based on personal observation (see Appendix D), it was also concluded that more durable attachments needed to be used rather than the current system of velcro and/or tape. This problem was solved by a holder that uses screw threads to hold the microswitch, which maintains its hold on a button almost indefinitely.

Figure 5: Microswitch holder

Discussion of Future Development

The following steps are recommended to further improve the design of the stand alone articulating button holder.

Improvements:
The base of the design could be further optimized for stability against the amount of space it takes up, which would further ensure rigidity during use, and also make the maneuvering of the design in to place more efficient for the therapist. Construction out of more rigid materials would add to the increase of stability to size relationship.

The loosening and tightening of the joint adjustments could be further developed beyond wingnuts for a more ergonomic design that can be turned more precisely and easily by the therapist. It could also give the design a more professional appearance.

The overall design could house more obvious visual cues for how to adjust each component, which would almost completely eliminate any concern for confusion with the use of both the height adjustment and the angle adjustment of the arms.

Testing:
The initial patient that would be the recipient of this design is no longer in the AbilityLab. More user testing of the button holder with other users to gather a more varied opinion would help to further optimize components of the design to fulfil specific requirements as well as minimize possible limitations.

Only one iteration of the design is made for submission as the final prototype. Testing other expendable iterations of the device for durability with more rigorous strength and use tests would provide valuable information to optimize dimensions and materials of components to maximize structural integrity and minimize the impact of potential failure points.

Conclusion

To conclude, our design meets the requirements the fundamental needs of both the therapist- who positions the device so it can successfully be used by the patient-- and the patients themselves, who will now be able to enjoy a full gaming therapy session uninterrupted. The design does this by:

- **Jointed arms:** Allows for full rotational adjustability, allowing the therapist to position buttons close enough to the face and shoulders where they can be used without falling away from these positions
- **Vertical adjustment:** Easy adjustment for patients with different heights allows for setup to only require few movements between patients
- **Standing alone:** Ensuring that the therapist doesn't need to be interfering through all stages of the session, just for setup and teardown

The design is also made from lightweight materials so that it can easily be transported throughout the lab to where it is needed and can be used easily by not only the therapists but also possibly the patient's families, which was an important requirement for the client.

Appendix A: Project Definition

Project Name: Adaptive Gaming Solutions
Client: Shirley Ryan Ability Lab (project partner Jordan Huffman)
Team Members: Frank Burke-Olson, Reilly Hannula, Maya Lundell, Antony Traino
Date: 11/7/19
Version: 3

Mission Statement: Our mission is to design a device to position and hold buttons in place to allow people with severe spinal cord injuries to engage in adaptive game play independently and for an extended period of time. Additionally, setup by the therapist will take less time than the current solutions and take less intervention.

Project Deliverables:

- Final Report
    - Include appendices
- Presentation and poster during the design exposition
- Physical prototype

Constraints:

- All deliverables are due on December 7, 2019
- The project budget is $100
- Any design solution must not encumber the patient's vital functions

Users and Stakeholders:

- **Jordan Huffmann, user and client**. Will use the device to assist her patients in playing video games.
- **Shirley Ryan AbilityLab patient.** Will be assisted by the device helping them to play video games.
- **Additional AbilityLab patient.** Potentially will use the device in conjunction with the primary AbilityLab patient.
- **Additional AbilityLab therapist.** Potentially will use the device to assist the additional patient in playing video games.

User(s) Profile:

- Jordan Huffman is an occupationall therapist at the Shirley Ryan AbilityLab. She works in rehabilitation with pediatric spinal cord injury patients who have varying

degrees of paralysis. She works to help them strengthen their available mobility and regain their independence for day-to-day living
- Shirley Ryan AbilityLab patient. Children with ages ranging from late childhood to early adulthood. They have varying levels of functionality and control of their extremities. The device will be adjustable to accommodate the user. Patients have no mobility below their shoulders and limited movement of their head and shoulders. Device should be designed to accommodate the users' range of motion.

User Scenario:

Kylie wheels herself into the game room at the top of the hour, ready and excited to play a video game. Jordan Huffman, her occupational therapist, prepares the buttons necessary for gameplay, gathering a velcro straps to assist with the setup. Kylie waits patiently while Jordan struggles with the velcro, bending the straps in an attempt to securely fasten the buttons to Kylie's wheelchair. When she steps back from what she thinks is a functional setup, she discovers that some buttons are too heavy and will not stay, or dip at too harsh of an angle, and she breaks out more velcro to reinforce connections and hold proper angles. Finally Kylie is ready to play. The game begins and she is pressing buttons with her head, shoulders, and tongue when, to her dismay, her shoulder pushes the entire button upwards instead of pressing it. She tries to get Jordan's attention to notify her of this problem. For the next five minutes, Jordan tries to reposition the button so it can be pressed, but it just will not stay in place. Finally, she gives up and holds the button above Kylie's shoulder with her hand. Over time, Jordan's positioning of the shoulder button deteriorates, and Kylie needs to remind her to correct the position once again. Not much later, the gaming session is over, and each button is removed from the wheelchair, each piece of velcro is carefully removed from the button, and each button is then sent away for individual cleaning and sterilizing. Jordan hopes that one day Kylie will be able to play video games without having to worry about how long the setup will be and how long it's position will remain functional during gameplay.

Requirements and Specifications:

Categories	**Requirements**	**Specifications**
Adjustability	The final product must be able to position at least four buttons in a location reachable by the patient.	Device must be able to hold at least 4 buttons within at most one inch from the part of the body that will activate

	Additionally the buttons must be accessed by users from a range of sizes. *Rationale:* The patient will not be able to play if they cannot touch the buttons	it, whether that be the shoulder, the cheek, the mouth, or the temple. The Triple Elbow achieves this. *Rationale:* Buttons placed farther away will not be within reach. Client said buttons should be placed within an inch of the patient's shoulder or head. With a wide range of motion, users with a range of sizes will be able to use the product. The joints of the Triple Elbow, as shown in Performance Test, can be configured as close or as far away from the body as needed. Also according to Performance Testing (Appendix G), we found that the Triple Elbow can accommodate our smallest team member (5'1) and our largest team member (6'1).
Independent Gameplay	The final product must enable the patient to play a video game for a length of time without the aid of Jordan or another therapist. *Rationale:* The therapist expressed desire to increase patient independence.	Button should be able to withstand a thousand presses at 0.5 lbs of force without losing its ability to be pressed by the patient. *Rationale:* Jordan Huffman stated that with the current system, buttons come out of place with use and constantly have to be readjusted. The force produced by the user Lenny was never over 0.375

		lbs. The device should be able to easily withstand the forces applied by the user. Additionally, the average frequency of button presses observed at the user observation was once every 4 seconds. If the session lasts one hour that would be 900 presses. (Appendix B and Appendix D)
Set-up and Tear-down	The final product must be able to be set-up and torn down without the use of external tools. Additionally, the device must be able to move device out of the way if there is an emergency or when the session is over. *Rationale:* The product must be an improvement over the current solution which requires the use of external tools for set-up. Also, the safety of the client is of utmost importance.	Setup time must be no more than 15 minutes, and teardown must be no more than 5 minutes *Rationale:* A normal length of therapy for Jordan Huffman is 1 hour. In a client meeting she stated that she would like at least 40 minutes of independent game play for her patient. Therefore setup must not take more than 15 minutes and the teardown must not take more than 5 (Appendix B). Our setup from scratch took 3 minutes and our teardown took just 1 minutes (Appendix G).
Mobility	The final project must be able to move around easily and without struggle *Rationale:* The device will likely be set up by only one person	The device must be no more than 100 pounds on wheels. *Rationale:* The use of a wheel decreases the force needed to move an object. The therapist needs to be able to push a person in a wheelchair to

		perform their job, so the device must be no heavier than a person on a wheelchair. The lightest patient we interacted with at Shirley Ryan weighs approximately 62lbs without a wheelchair, which is considerably heavier than the Triple Elbow.

Table 2: User Requirements

Appendix B: Client Interview Summary

The following is a summary of information provided by our client Jordan Huffman, an Occupational Therapist at the Shirley Ryan ability lab. This interview was conducted on September 26, 2019 at the Ford Motor Company Engineering Design Center at Northwestern University.

Objective

The objective is to design a device to position and hold buttons in place to allow people with severe spinal cord injuries to engage in adaptive game play independently and for an extended period of time.

The Shirley Ryan Ability Lab

The Shirley Ryan AbilityLab serves as a rehabilitation facility for patients of all ages with brain injuries and physical complications. The types of rehabilitation programs they offer include

- Speech therapy
- Occupational therapy
- Physical therapy

Our team is working to improve the lives of patients with severe spinal cord injuries that have resulted in paralysis from the neck down. They have no mobility in their hands or arms, and limited mobility of the shoulders, neck, or face. They require 24-hour care and ongoing rehabilitation for three hours a day with the goal of regaining and strengthening the use of some muscles.

Our client specializes in pediatric rehabilitation, and works with patients ranging in age from infancy to early twenties. She works alongside a Child Life Specialist to engage her patients in daily living activities through therapy.

<u>How Spinal Cord Injury is Addressed</u>

At the Shirley Ryan ability lab, patients with higher level spinal cord injury participate in occupational therapy, with the goal of learning how to go about their everyday activities with independence. Adaptive video gaming is a way for therapists to accomplish this. Within gameplay patients exercise their movements by controlling the game with various switches for both a therapeutic and fun activity.

Current Solution

The current system employed by the Shirley Ryan AblityLab centers around the Xbox Adaptive Controller used in combination with the devices already available to the staff. These include:

- Microswitches: The most sensitive of the controls, microswitches only require slight pressure to activate and are typically placed around the face
- “Jelly buttons”: Typically placed above the patient’s shoulders and activated by a vertical shrugging motion. Sometimes placed on either side of the patient’s head depending on the user’s range of motion. Slightly more strength required to activate than a microswitch.

Therapists currently use tape and velcro or their own grip to position these controls around or directly onto the patient’s wheelchair and hold them in place for gameplay.

<u>Drawbacks to the Current Solution</u>

There are many ways the current solution acts as a barrier to effective and enjoyable gameplay. According to our client, the drawbacks are as follows:

- **Prolonged setup:** Setup of the system currently takes a minimum of 15 minutes, and it tends to lose its structure as the gaming session progresses. This is time that takes away from actual treatment time
- **Not adaptable:** The improvisation of the current setup means it can’t simply be moved from patient to patient. The setup also must be dismantled at the end of every session, and the therapists start from scratch to recreate it at the next one.
- **Reliant on therapist involvement:** Patients can’t play fully independently and must rely on a therapist to make minor adjustments, and therapists must remain at the side of the patient.
- **Inhibits functionality:** Because switches must be fastened directly to the wheelchair, it is easy for patients to accidentally trigger two switches at once which interferes with proper gameplay

There are also some solutions that have been suggested and even attempted by the Shirley Ryan Ability Lab, but have also presented a few drawbacks:

<u>Tongue switch</u>

- Benefit: Allows for a more dynamic gameplay. Patients can play more complicated games if they are willing to use this control with their tongue
- Drawback: Not preferred by older patients

Headpieces

While a headpiece might seem like a viable option for a solution, they can be uncomfortable for an extended amount of time. However, it would allow the controls to be centralized and in close proximity to the patients.

Microswitches

- Benefit: Most successful of the controls, easy for the patient to trigger
- Drawback: Expensive and can accidentally be triggered, so there needs to be room for other options as well to minimize misinputs

Gooseneck mount

- Benefit: Easily adjustable and very flexible, can get components close enough to the patient where they can access them for gameplay
- Drawback: Expensive, bulky, and are not sturdy enough to hold buttons in the correct position for the entirety of the gaming session

Direction for Design

Therapist Needs

The ultimate goal for the therapist is to create a rig that is easier to set up and adjust that works more efficiently than the current system of tape employed. The following need to be improved to reach this goal:

- **Increasing patient independence by decreasing the need for therapist intervention**. Ideally, the rig should take no longer than 15 minutes to set up and not much longer than five minutes to disassemble if necessary, and the therapist should only have to be involved in the setup itself.

- **Decreasing the amount of unstable objects** such as gooseneck mounts, tape and velcro.

Patient Needs

Kylie, the primary user of the adapted video game controlling system, likes to play Candy Crush, Mariokart, and Minecraft. To continue to play these games, the final design should preferably meet the following criteria:

- **At least 4-6 points of contact** to activate multiple controls while playing any given game.

- **Flexibility based on the size of the person and the wheelchair** as well as their particular range of motion and comfort level.

- **Elimination of the headrest** as a mount for buttons. Ideally, the contraption would be completely independent of the wheelchair, but at the very least it should not be placed on the headrest.

- **Adaptability for use out of the lab**. A patient's family should be able to set up the device within the confines of their own home.

- **Practical while remaining enjoyable**. The patient should be able to fully enjoy their game while also being able to grow their muscle endurance in their shoulders, neck, and face.

Appendix C: Background Research Summary

To start our project, our team conducted research on the terms and products mentioned in both in an interview with our client -- Jordan Huffman, a physical therapist at the Shirley Ryan Ability lab -- and in a written description of the proposal. Our task involves designing a device that will assist in the setup of an adaptive video game system for patients with severe spinal cord injuries. The following is a summary of our findings in the areas of

- The details of spinal cord injury
- Adaptive video gaming technology
- Model Products

Spinal cord injury

Spinal cord injuries occur at various levels of severity and are classified by the location of the damage. Jordan works with patients who have sustained injuries to the top four vertebrae of the neck, with the top vertebrae labeled “C-1,” the one beneath labeled “C-2,” and so forth. This type of spinal cord injury is classified as a “cervical spinal cord injury” and typically results in loss of function of legs and arms and affects movement in the stomach and chest. This type of damage to the spinal cord is also known as Tetraplegia or Quadriplegia.

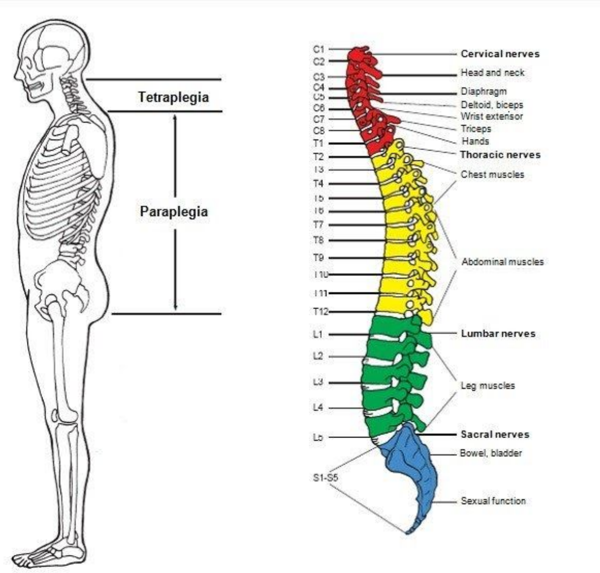

Figure 6: Levels of Spinal Cord Injury
Source: “What is Spinal Cord Injury (SCI)?”
<https://www.motivation.org.uk/what-is-spinal-cord-injury-sci>

Figure 6 shows how the location of the damage affects the patient's mobility. In our case, we are working with patients who have sustained C1-C4 damage.

Adaptive Video Gaming

Therapy for pediatric patients with SCI at the Shirley Ryan ability lab includes engaging in video games. However with the limited mobility of the patients, they play games a little differently.

<u>Xbox Adaptive Controller</u>
The Xbox Adaptive Controller allows gamers with limited mobility to engage in gameplay. It works alongside a range of external devices that are simply plugged into the hub.

Figure 7: Xbox Adaptive Controller
Source:
<https://www.xbox.com/en-US/xbox-one/accessories/controllers/xbox-adaptive-controller>

The two large buttons and d-pad are for simple controls for patients who can move their hands, but not their fingers. There are over 19 ports on the back of the controller where peripheral buttons and switches can be assigned to specific controls.

If a gamer cannot operate all of the necessary controls, the device features a "copilot mode" in which someone who is able to operate a regular controller can play alongside the adaptive gamer and assist in gameplay.

<u>Other adaptive gaming technology</u>

Besides the Xbox Adaptive Controller there are other technologies that can be integrated to making gaming more accessible to patients with limited mobility. These include:

- **Sip and puff**: Sip and Puff or "Sip n' puff" technology utilizes a straw into which users either inhale or exhale and the resulting changes in air pressure send signals to a device.

- **QuadStick:** The QuadStick is a game controller that is mouth operated and integrates Sip n' Puff technology and lip position sensors. It is directly compatible with a few of the major gaming systems including PS3, PS4, Nintendo Switch, Windows PC and Mac computers. All models of the QuadStick controller are fairly expensive, with prices within the range of 400-600 USD.

Figure 8: Sip n' Puff Switch
Source: <https://enablingdevices.com/product/sip-and-puff-switches/>

Figure 9: QuadStick Controller
Source: <http://www.quadstick.com>

Model Products

There are a few products that we feel may serve as useful models as we consider designs for our final solution. The following are what we would consider model products.

<u>Adjustable Hurdle</u>
Push button adjustment locks allow hurdles to be adjusted to different heights while remaining secure in each position. Our product needs to be adjustable to different patients, so this technology serves as a good model in terms of flexibility.

Figure 10: Adjustable Track Hurdle
Source: <http://trackinfo.org/hurdles101.html>

Adjustable Aluminum flagpole bracket
By unscrewing the bolt in at the center, the angle of the flagpole bracket can be adjusted with ease. Adjustments can be fine or drastic and the bolt holds whatever position the user decides upon in place. Buttons and switches might be fastened to a product in this way.

Figure 11: Flagpole Bracket
Source:<https://www.flagsimporter.com/adjustable-aluminum-bracket?gclid=CjwKCAjw5_DsBRBPEiwAIEDRW1xNTBAb15jEMn4J8w-5qo1UTz_JUjUH5_FgKheWYgwYjIs_KziucxoCUfQQAvD_BE>

Overbed Table
An overbed table is both vertically adjustable and can roll up alongside another piece of equipment such as a bed or a wheelchair while allowing for a usable surface that hovers over the patient.

Figure 12: Overbed Adjustable Non Tilt Table
Source: < https://www.walmart.com/>

REFERENCES

Machkovech, Sam. “In the Lab with Xbox's New Adaptive Controller, Which May Change Gaming Forever.” *Ars Technica*, 17 May 2018, arstechnica.com/gaming/2018/05/xbox-adaptive-controller-a-bold-answer-to-the-tricky-world-of-accessible-gaming/.

“QuadStick.” *QuadStick*, www.quadstick.com/.

“Sip ‘n’ Puff Technology.” *Disabled Sailing Association of British Columbia* , www.disabledsailingbc.org/sip-n-puff.html.

“Spinal Cord Injury Information.” *Spinal Cord Injury Information: Levels, Causes, Recovery*, www.shepherd.org/patient-programs/spinal-cord-injury/about.

WeAreMotivation. “What Is Spinal Cord Injury (SCI)?” *Motivation*, www.motivation.org.uk/what-is-spinal-cord-injury-sci.

“Xbox Adaptive Controller: Xbox.” *Xbox.com*, www.xbox.com/en-US/xbox-one/accessories/controllers/xbox-adaptive-controller.

Appendix D: User Observation Summary

Introduction

The observation of people with quadriplegia and their therapists and how they currently play video games took place at the Shirley Ryan AbilityLab in Chicago on Thursday, October 3. The purpose of this observation was to:

- Identify materials and devices used by the Shirley Ryan AbilityLab to allow their patients to play video games
- Locate points where the current system is working, and where the current system can be improved
- Note how the patient interacts with the video game, their own wheelchair, the therapist(s), and the surrounding environment

Outline of Observation

The visit took place on the 18th floor of the facility, where our project partner Jordan Huffman works with patient Kylie, a ten year old girl with quadriplegia. One other girl around the same age as Kylie with quadriplegia and her therapist were also present. The plan was that, working together, Kylie and the other girl were going to spend some time playing a Frozen-themed version of Candy Crush. After playing that game for a while, they moved on to Sonic Racing. This lasted for about one hour.

During the gameplay, the therapists were asked questions about the current system of adaptive video controllers and what they felt could be improved. Meanwhile, various aspects of the patients' wheelchairs were measured as well as some of the buttons and other devices. The patients were being constantly observed to determine the positives and negatives of the setup, as well as the patients' personal feelings toward the device.

About the Observation:

<u>System Parts</u>

During gameplay, multiple aspects of the video game system were shown. The following are physical aspects of the system, including materials used to attach the pieces to the wheelchair and person, as well as the buttons themselves:

- **The items they have to work with are** 2 jelly switches, 3 microswitches, 1 large microswitch and 1 nunchuck.

- **The controllers are moved or can be used by** moving forehead, sides of head, cheeks, shoulders and tongue.
- **Velcro is used and disposed** as they are used to hold the jelly buttons in place but often get grimy and sticks together less.
- **Xbox controller sat in the middle** of the two patients on a table. Wires were explicitly stated as not an issue for the current setup, as the Xbox controller was so close to the two patients.
- **The basic plug is a USB** but that is the only control change dealt with. We don't have to change button placement between games, just the plugs in the Xbox controller.

<u>Patient Observations</u>

The primary users of the system were Kylie and another patient of the same age. Kylie ultimately controlled the most buttons (assumedly based on her experience), but the two girls still worked together with a total of six buttons to control the Candy Crush-like game and Sonic Racing. The following were observations about the ability of the patients to use the system.

- **The patient playing with Kylie had buttons attached to the headrest** right behind her ear. She could activate them by moving her head from side to side. Average frequency of button presses was once every 4 seconds.
- **Kylie could use a nunchuck** with her mouth when it was taped to the rigid arm reaching around her head. However, it is important to note that not everyone has this rigid arm.
- **The patients would not be able to use the "sip and puff" device** because it seems to be unreliable as well as hard to connect to the Xbox Adaptive system.
- **The patients do not complete complex movements**, but usually continuously push a single button then switch to another one. More experienced users like Kylie, however, are able to move a controller like a nunchuck with their tongue and are able to perform more complex moves.
- **How well the setup works is partially based on user experience.** Kylie was more fluent with her movement but only because she had been playing video games for a while. Her partner was less sure of herself.

<u>Therapist Observations</u>

The current video game system is run by the patients, but set up by the therapists. Before actual gameplay, multiple therapists were involved in attaching buttons to the wheelchair and adjusting the buttons based on patient size and preference. However, they were also involved during gameplay as they needed to hold up buttons that had moved out of place. The following were observations about the role of the therapists:

- **Setup started at 2:05 and took until 2:18** which allowed for only about 40 minutes of gaming.
- **Two therapists stood directly behind the patients** and Kylie's therapist held a button up to her shoulder so Kylie could activate it. The therapist held the button in the same position for about half of the gameplay time and then moved to the other shoulder.

Directions for Design:

Function Requirements

Throughout the observation session, the project partner and her co-workers expressed what they thought were the most important aspects of the potential design. The following are client requirements that pertain to the function of our design.

- **The device should have 4-6 buttons** per person. This means mounting all of them on the device to allow them to activate at least 4 controls at a time.
- **The device should be able to stand** independent of the wheelchair
    - Using the headrest for support is good for a rig, but the therapist prefers the device to stand alone rather than be on the wheelchair to maximize adjustability.
- **The device should be adjusted** based on the size of the wheelchair being used or the body of the patient.

Material Requirements

The following are client requirements that pertain to materials in our design:

- **The device should be made of materials that can be cleaned and are stable** considering the current materials easily get dirty and unattached.
    - Putting things near the shoulder is challenging because they can easily get knocked out of their position. Anything near the shoulder will need to be secured by a rigid material.

Other Requirements

Beyond the function of the device and materials used, the client also expressed that the device should be able to be cleaned without negatively affecting the material. Another preference is that the device should be affordable, since the therapist conveyed that having families use the device at home would be beneficial.

Measurements:

These are potentially useful measurements for the creation of an improved adaptive video game controller:

- Wheelchair arm: 1'' by 2''

- Wire length of buttons: 54’’
- Distance from arm to face on wheelchair: 18’’
- Width between headrests: 9”
- Wheelchair: 18” wide for Kylie, possibly larger for other users
- Small micro-switch: 1 ½” x ¾” x ½”
- Base of wheelchair: 30” x 28”
- Buttons: use mono 3.5 mm jack
- Height of wheelchair: 50’’

Initial Ideas:
After observation, we began to consider some ideas for our design. This includes design ideas, model and competitive product, and inspiration from suggestions of the therapists at the AbilityLab. The following were the ideas that came from our observation of the Xbox Adaptive video game controllers:

Observations	Opportunities	Follow-up
BUTTONS: The therapist was forced to constantly readjust and even hold buttons to allow for comfortable gameplay	Find a way to hold the buttons in place without the therapist having to hold it	Potential design: A rigid button holder to slide buttons into place so they don’t move, and mechanism to rotate button holder for access to multiple areas of the body
FRAME: Various parts of the system were attached to the wheelchair which made set-up and take-down more difficult	Provide a device or system independent of the wheelchair, preferably in one piece instead of multiple smaller pieces	Potential Design: Structure based off the Swedish Sling (a frame going above the wheelchair to help movement), or a structure that can be attached to a bedside table and be level with the patient
ADJUSTABILITY: The system was not adjustable or difficult to adjust when using it across multiple people	Create simple areas for frame adjustments vertically, horizontally, and regarding button placement	Potential Design: An extension mechanism like that on an adjustable medical table, hurdle, or crutch to allow for vertical adjustability

Table 3: Initial Prototype Ideas

Appendix E: Description and Analysis of Alternatives

Three-pronged Tension Holder

The three-pronged tension holder is a rigid tripod of plastic sticks protruding from a central rod. The ends of the prongs can be bent inwards or outwards to any position to latch into any holes or gaps in an object. The force of tension from the prongs trying to return to their unbent state should overcome gravity to keep an object suspended above the ground.

The therapist should interact with this mockup by positioning the three prongs in their respective holes around the circumference of the button, then subsequently inverting the system to keep the button suspended. The patient should then press the button—either on or off the button holder—exactly like they do during a gaming session to allow observation of strength.

The purpose of this mockup is to determine whether the tension of the button holder is enough to keep a button with three small holes suspended in the absence of any major form of friction, as well as to quantify with a visual reference the strength with which a patient presses the button for use in future testing.

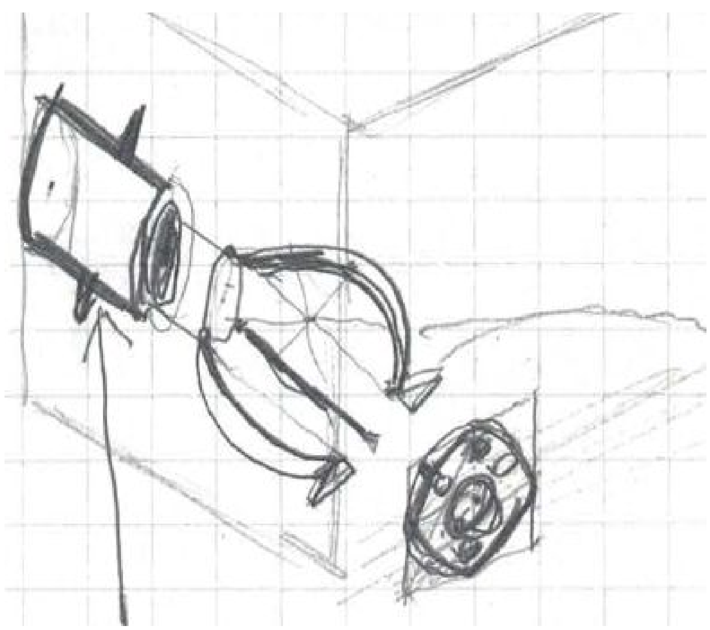

Figure 13: Sketch of Tension Holder

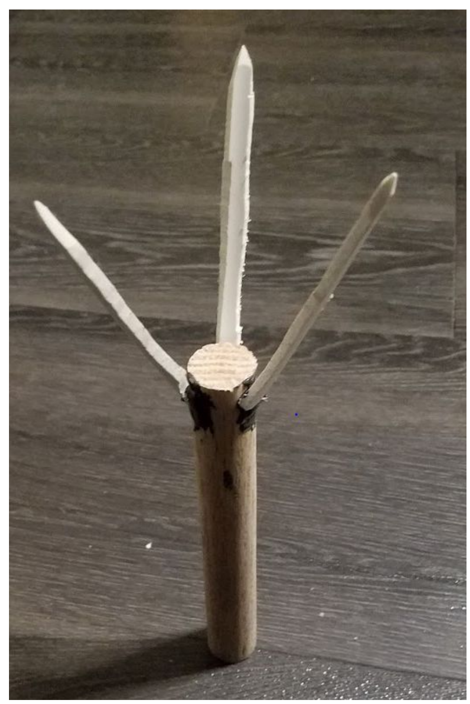

Figure 14: Image of Tension Holder

Flexible Measuring Reference

The flexible measuring reference is a length of flexible material that holds its shape after bent, allowing it to be set in a position and then removed while still maintaining its geometry from the positioning. The therapist should interact with this mockup by holding the reference against the patient's head so one end lines up with the patient's ear, and the reference wraps around to the front of the head to allow measurement of length.

The purpose of this mockup is to determine the length a bendable stick originating at the ear would have to be in order to reach around to the front of the mouth. The measurement will be used to design a final product of a similar shape so that it will fit and adjust properly on anyone's head.

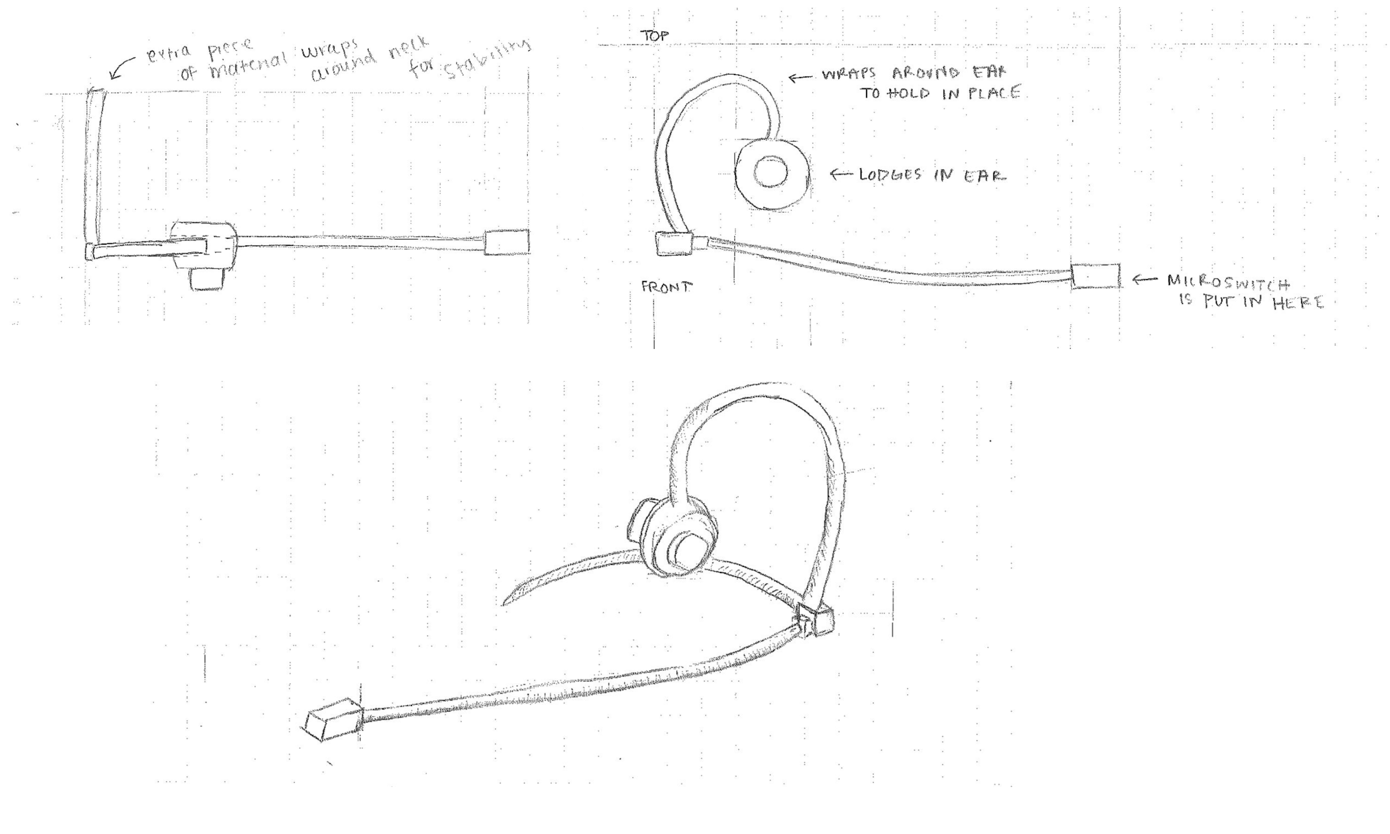

Figure 15: Sketch of bendable stick based on Flexible Measuring Reference

Figure 16: Image of Flexible Measuring Reference

Three Dimensional Rotational Angle Adjustment Module

The 3D rotational angle adjustment module is a set of two spherical knobs sandwiched between slots which allow the knobs to rotate without coming free. When a wingnut screw holding the two slots together is tightened, the knobs are more tightly held, completely restricting their rotation and holding their position rigid. The user should interact with this mockup by attempting to forcibly move the knobs, then unscrewing the wingnut screw and attempting to move the knobs again, followed by tightening the screw once again.

The purpose of this mockup is to determine whether the tension from the screw on the slots provides enough force to completely keep the spherical knobs from rotating. Also, this mockup will be used to test whether a wingnut screw is an intuitive, easily accessible tightening method against other methods.

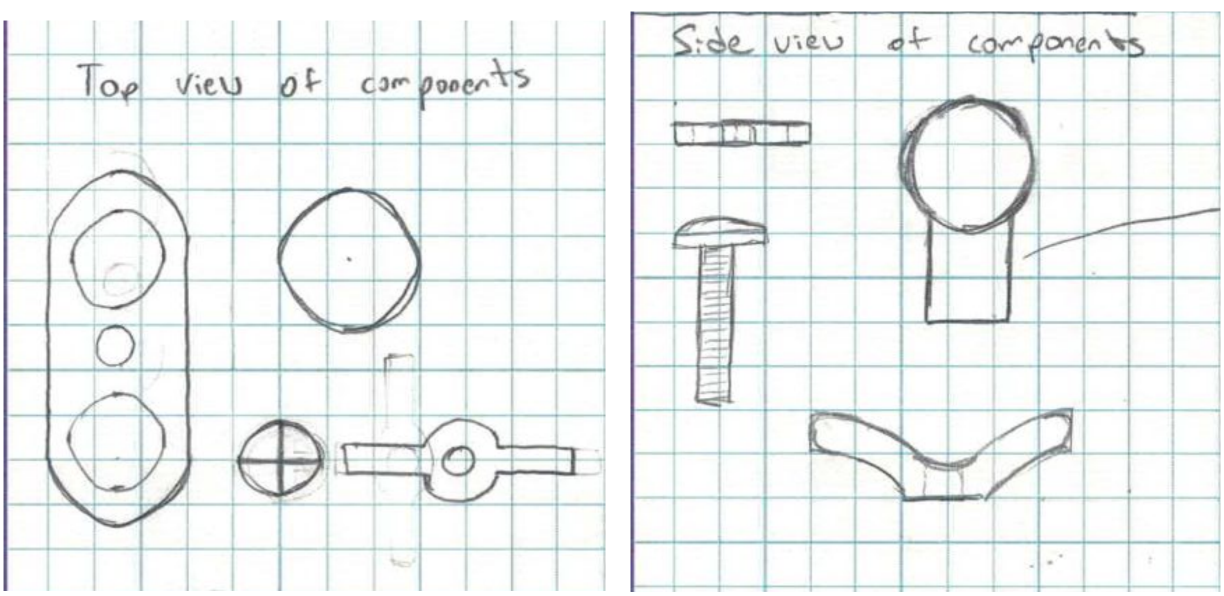

Figure 17: Orthographic sketch of 3D Rotational Angle Adjustment Module

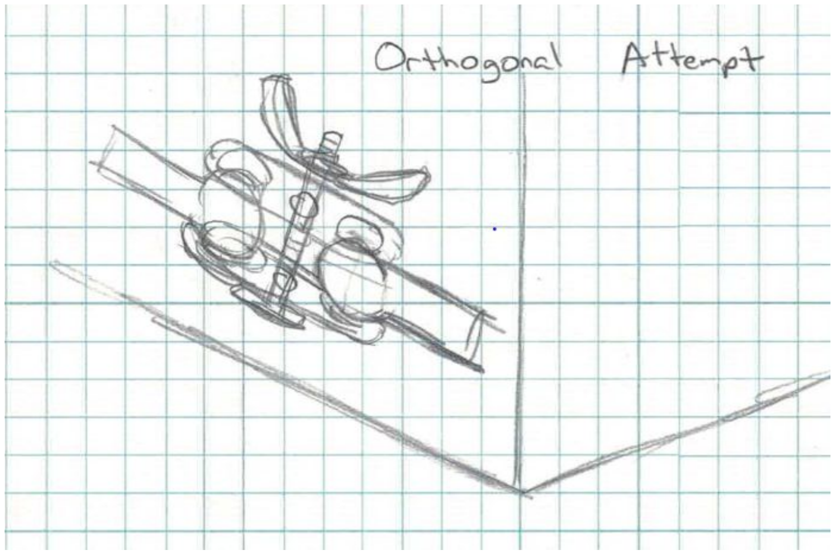

Figure 18: Isometric Sketch of 3D Rotational Angle Adjustment Module

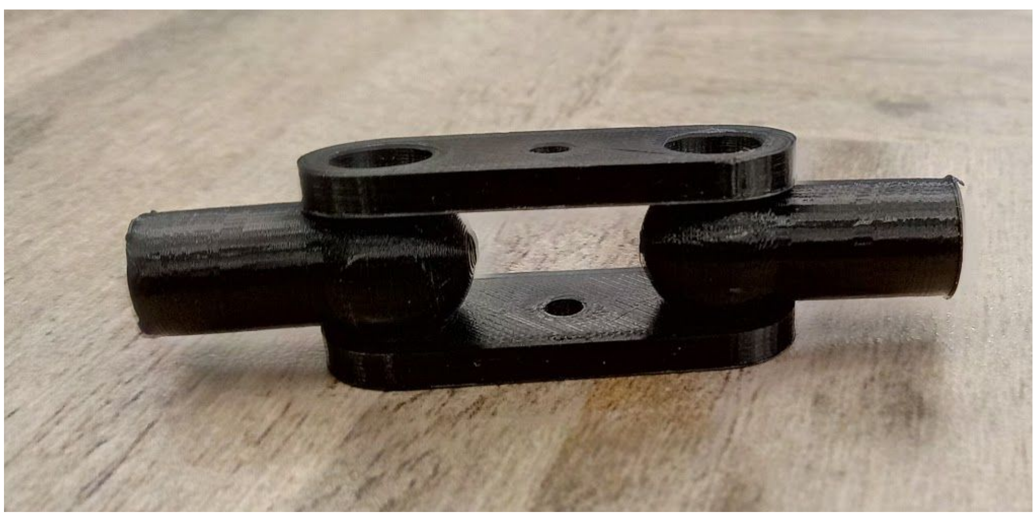

Figure 19: Image of 3D Rotational Angle Adjustment Module

Articulating Arm with Angle Adjusting Module

The articulating arm with and Angle Adjusting Module is a series of flat, rectangular segments of rigid material with varying lengths connected by metal joints that allow the segments to rotate fully on a two-dimensional plane. The user should interact with this mockup by attempting to rotate the various segments of the arm in order to reach different positions.

The purpose of this mockup is to determine whether a segmented design is an intuitive solution for enabling an arm to reach a variety of positions. This mockup also provides a guideline for the length that an arm will need to be in order to comfortably position a button for patients of any size while not occupying too much space.

Figure 20: Image of Articulating Arm with Angle Adjusting Module

Appendix F: Design Review Summary

The following is a summary of feedback given about the initial design from our peers, design professors, and design experts.

Reviewers like:	Reviewers dislike:	Features to be added	Features to be removed/modified	Additional comments
<u>ADJUSTABILITY</u> Push-button lock mechanism for vertical adjustment Comes around the wheelchair	<u>ADJUSTABILITY</u> Amount of things that need to be adjusted - joints might be particularly tedious Potentially not enough places to put buttons - setup needs to be versatile for where each person wants each button <u>USE IN PLAY</u> No sure way to hold buttons if they will be upside down, suggested to screw with bigger head so when you screw in you wouldn't be able to move it	<u>FRAME</u> Large base with heavy materials so that the pole does not tip over - heavy material OR if tube frame, but sand inside Cross bars around the base for stability	<u>FRAME</u> Two poles to hold buttons instead of one central pole - also add diagonal poles for stability Instead of tightening the button holders with screws, use a mechanism like a phone holder in car	Reviewers asked what potential materials we would be using: steel and PVC Recommended threaded inserts for full movement of joints

Appendix G: User Testing Results

Purpose:
The purpose of this round of user testing was to assess the efficacy of our mockups and iterations for holding the buttons that connect to the Xbox Adaptive Controller. This included determining the lengths of the sections of articulating arm that would best provide a full range of motion while also keeping the device as small as possible. The feasibility of the three-pronged tension holder was tested as well taking measurements and receiving user input on the head mounted microswitch holder.

Test Methodology:
On the week of October 28, the four team members conducted a mockup testing session at the Shirley Ryan AbilityLab. Multiple separate elements of the device were tested to confirm dimensions and test the functionality of the prototypes. Multiple user interfaces were presented to the client, Ms. Huffman. Feedback on said interfaces was received to ensure that the client would be comfortable operating the device.

Figure 21: Cardboard mockup of articulating arm being tested for length.

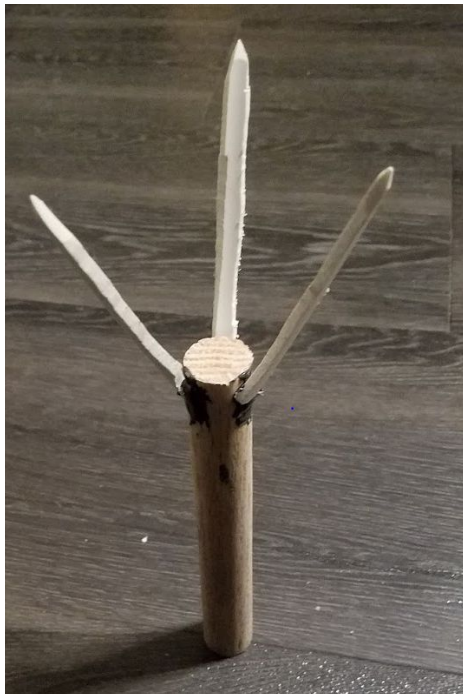

Figure 22: Three-pronged tension holder

Figure 23: Clamping style button holder mounted to the button

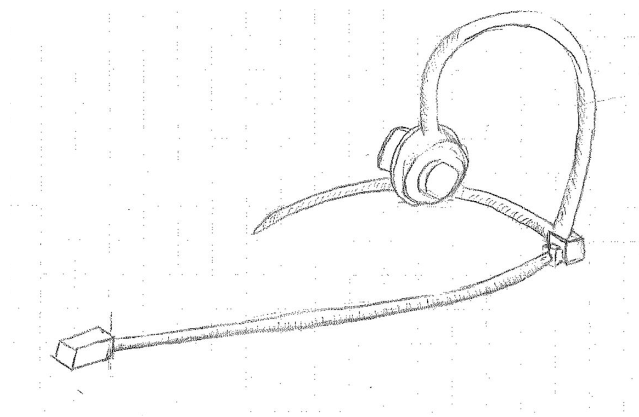

Figure 24: Sketch of head mounted micro switch holder

Figure 25: Spring clamp

Tests were performed in accordance to the methods outlined in a performance testing guide.

Figure 21: Shows the testing of a cardboard mockup of the articulating arm. Starting with very long lengths of each segment of arm, the cardboard was cut until the optimal lengths were achieved.
Figure 22: Shows the three pronged tension holder that was tested on its ability to hold the button with its three protruding prongs.
Figure 23: Displays a new prototype for holding the button. It uses 3 posts that insert into the holes in the button similarly to the three pronged tensioner. However, it relies on the posts being pulled together by a bolt to provide the clamping force.
Figure 24: User feedback was received from the patient Lenny about the comfort of the head mounted micro switch holder. Lenny also was prompted to actuate the large button using his head with both normal and excessive force. Due to the lack of a force measuring instrument, only an approximate force was recorded.
Figure 25: A possible method for attaching the articulating arm to the user's wheelchair. The button holding methods were tested on how well they could hold onto the button. Ms. Huffman

tested the spring clamp by testing if she was able to fully open it with one hand, and was able to clamp it on the patient's wheelchair or a tear by table.

Results:

This table relates length of arm segments on the articulating arm to ease of use.

	Segment 1 (Connected to chair)	Segment 2	Segment 3	Segment 4 (Button holding side)	Feedback
Trial 1	18"	18"	12"	12"	Arms were too long. Unwieldy and unnecessary.
Trial 2	12"	18"	12"	12"	Lengths seemed to balance reach with usability.
Trial 3	12"	12"	12"	12"	Arms were too short. Unable to reach all positions
Trial 4	12"	12"	12"	18"	Long segment was awkward because of its location.

Table 4: Trials of Arm Segment Lengths

This table is an estimation of the force used by the patient to actuate the button with his head. To come up with an approximate actuation force, the force produced by Lenny was compared to the force of a weight being acted on by gravity.

	Normal actuation force	Excessive actuation force
Estimated force (Lbs)	0.125	0.375

Table 5: Force used on Button

The following discusses the success and failures of the three pronged tension holder, clamping style button holder, and head mounted button holder.

Three Pronged Tension Holder: Attempting to hold the button with the three pronged tension holder was unsuccessful. The prongs did not have enough grip on the sides of the holes in the button to maintain a steady affixment. A possible solution to this would be to increase the friction between the two surfaces.

Clapping Style Button Holder: Testing of the clapping style button holder also did not yield a success. The device was obstructed by the velcro mounted to the back of the button from earlier uses. Elongating the posts on the device would address for this non uniformity of the button surface.

Head Mounted Micro-switch Holder: It was determined that the head mounted microswitch holder would not be an ideal method for positioning the buttons. After discussion with both the user (Lenny) and Ms. Huffman, it was clear that the device would be unable to provide the required level of comfort and large range of adjustability.

The feasibility of using a spring clamp as a mounting method for the device was tested. The results are as follows:
Ms. Huffman was able to fully open the spring clamp with one hand as if she were going to attach it to either a table or other surface. She stated that everyone on her team of therapists would be able to comfortably operate the clamp. She did suggest that the clamp should have something to prevent scratching the surfaces that it is connected to. Spring clamps with a rubber overmolding would solve this problem.

Analysis, conclusions, and limitations:

<u>Analysis of results</u>

The following briefly goes over requirements of the design and how each element that was tested meets the posted requirements.

- The ideal setup for the articulating arm is a 12” segment to a 18” segment to a 12” segment to an 12” segment. This combination of lengths balances both maneuverability with the ability to reach all locations where a button may want to be placed. It also leaves some room for additional adjustability depending on the mounting location.
- Mounting locations may include: wheelchair arm, standalone rack located behind the wheelchair, or an adjustable height table (max height 55”, height of Lenny in wheelchair)

which can be located on the side of the user. Multiple mounting locations will ensure a wide range of users can be accommodated.

- The force used by Lenny to actuate the button was not anything more than expected, therefore the rigidity of the device is not of increased concern.
- Using a spring clamp as an attachment method is viable as long as a protective layer is applied to the clamping surfaces as to not damage the clamping locations. This allows for multiple mounting points to increase adjustability.
- The failure of both button holding methods requires new iterations of both methods based on the shortcomings. As a team, the clamping style button holder is favored for its slim design which will enable it to fit between the headrests of the user's wheelchair and the users head during use.

<u>Conclusion</u>.The results of testing our multiple mockups points to a final device with only one or two separate elements to hold and position the buttons. Although the elimination of the head mounted micro switch holder was disappointing, it will enable the team to unify our design into a simpler device with fewer separate parts.

Limitations. One limitation to our testing methodology was that we did not have an instrument to measure force with. This would be used to quantitate the force Lenny used to actuate the buttons so that later we would be able to test our prototypes with the same amount of force. Instead, an approximation was made and our device will be made to withstand a greater maximum force than necessary.

Appendix H: Performance Testing Summary

Our group met on Saturday, November 23rd at 1:30 pm in the Ford Design Center Workshop to observe the efficacy of our design elements for holding the buttons that connect to the *Xbox Adaptive Controller*. Each element was used in separate scenarios designed to assess their main functionalities.

Goals of testing:

1. Assess durability of button-holders (each button holder must maintain position and structural integrity after 1000 button presses).
2. Assess whether device meets the project requirements outlined in project definition:
    a. Adjustability
    b. Independent Gameplay
    c. Setup and Tear-down
    d. Mobility
3. Assess durability and ease of use of all structural components (Must be adjustable and movable with minimal force and hold its adjusted position with a reasonably strong force from any direction).

Test 1 (Jelly Button Holder):
<u>Requirement</u>: The button holder must keep the button suspended in place with less than an inch of deviation from its original position throughout 1000 button presses at 0.5lbs of force.
<u>Testing</u>: After 1000 presses at roughly 0.5lbs of force, the button holder's grip on the button did not change at all. Even when more force was used and when force was applied in horizontal and vertical directions, the button did not move a millimeter within its button holder.

Test 2 (Adjustment Arm Stability):
Requirement: The arms of the device must be able to hold a button within at most one inch from the part of the body that will activate it. The arm's placement must not change more than an inch from its original placement directly over a body part after 1000 button presses at approximately 0.5lbs of force (estimated by observing patients playing games).
Testing: With the device freshly built, the arm withstood 1000 button presses without its positioning changing at all, always returning to its original position. However, after repeated readjusting of the arm placements without loosening the adjustment wingnuts, two arms withstood 1000 button presses without deviations, while the other two arms lost their position and completely fell to their bottom resting position after only a few button presses.

Test 3 (Device Weight):

Requirement: Overall device must be on wheels and weigh no more than 100lbs, which is around the average weight of patients at the Shirley Ryan AbilityLab, in order to be easily moved about by therapist.
Testing: Final prototype contains mounted wheels and weighs 28lbs (less than half the maximum weight).

Test 4 (Device Length Adjustment):
Requirement: The four arms must be adjustable to achieve any location from 8 feet high to 0 feet high to within an inch of the desired location.
Testing: The device can extend to easily reach from the arm's length above the 66 inch tall base as well as all the way to the floor. The arm can also reach up to the arm's length (2 feet and 2.5 feet for both types of arms) in front of the base at any height from the floor to the top of the 66 inch base. With a newly built prototype, the device can maintain its adjusted position within 1 inch accuracy with ease, though after repeated use and adjustment the arm struggles to maintain its desired position without specific routing of arms or outside interference.

Test 5 (Device setup time):
Requirement: Device must take no more than 15 minutes to set up and no more than 5 minutes to take down in order to maximize therapy time.
Testing: From all arms being loosened and unadjusted as well as all height adjustments being at their lowest position (the floor), complete set up around a human was timed to take 3 minutes with two experienced users. Take down from fully set-up position to all joints being loosened and at their bottom position was timed to take 1 minute with two experienced users. Both time measurements are expected to be doubled for first time users, but will approach recorded values with each successive use.

Appendix I: Instructions for Use

INSTRUCTIONS FOR USING THE TRIPLE ELBOW

These are the steps to follow when using the Triple Elbow:

Initial Setup (done by therapist)

1. Place patient and wheelchair in the desired position between the fork of the base.

2. Adjust the vertical height of the arms by turning the wingnut on the vertical adjustment to the left partially to allow for movement. Move the metal plates up and down to the proper height for the patient, then turn the wingnuts to the right to tighten the metal plates.

3. Adjust the position of the buttons by turning the wingnuts holding the joint together to the left slightly. This will let the balls in the joints twist easily to the desired position. Once that part of the arm is put into position, tighten the wingnut by turning it to the right. Do this for each necessary joint until arms are put in position.

4. There are two types of buttons that can be put in place:
   - To put the jelly buttons in place, unscrew the wingnut to allow the edge of the button holder attached to the arm to move outward. Place the button in the holder. Screw the wingnut back in to tighten the hold of the edges on the button.
   - To put the microswitch in place, screw the switch onto the small screw attached to the end of the arm, inserting the switch on the single hole on the bottom of the microswitch.

ADD PICTURES FOR EACH STEP

Take Down (done by therapist)

1. Return arms to resting position by loosening all wingnuts slightly and letting the arms hang vertically.

Appendix J: Instructions for Construction

The construction of the triple elbow button positioning device has three main components, the base, the arms, and the button holders. Depending on the needs of the user said device is being constructed for, the base and button holders can be modified from the original.

Material/ Hardware	Qty
¾ aluminum round stock	4 ft
Zinc-Plated Steel Wing Nut	25
½ inch PVC pipe	9 ft
Rubber casters	2
Lock Washers	12
2x4 lumber	8 ft
¾ " by ⅛ " flat stock	4 ft
10-32 by 1 ¼ " bolt	25
1" by 2" extruded aluminum channel	5ft
2 ½" deck screws	6
¼" Alumnium plate	6" by 6"
M1 x 2 bolt	2
5/16 -18 nut	4
5/16 -18 2" bolt	4
¼" Plastic sheet	6" by 6"

Table 6: Materials Used in Construction

Note: See Bill of Materials in report for details on cost, part numbers, and part numbers.

The following tools were used to construct the Triple Elbow:

- Band saw/Hacksaw
- Programmable lathe
- Mill, drill press, or hand drill
- Assorted metal files
- Various drill bits and taps
- Scotchbrite pad
- Five minute epoxy resin

Constructing the Base

- Screw two 30” 2x4s and a 40” 2x4 un a U shape.
- Drill 4 x 5/16 holes in the center of the main cross member in a rectangular pattern that matches the distance between the slots in the aluminium channel
- Bolt the aluminum channel to the wooden base using the 5/16 - 18 bolts and nuts.
- Cut the 6” by 6” plastic in half across the diagonal to make 2 identical triangles.
- Screw the plastic triangles into the corners of the wooden base to increase rigidity.

Figure 26: Base of the Triple Elbow

Constructing the Arms

- Cut the ½” PVC pipe to 6 x 1’ lengths and 2 x 18” lengths.
- Using a bandsaw, cut the ¾” aluminium round stock to 2” pieces.
- Using a manual lathe, turn the first 1 ¾” of the 2” sections down to ⅜”
- Mount the blank in the programmable lathe and cut the contour to create the ball end
- Scotch Brite the finished aluminum ball ends to remove any burrs
    - Using five minute epoxy, affix the ball ends into the ends of each PVC pipe
- Cut the ⅛” x ¾” stock into 2 ½” sections.
- Drill a ½” hole ½” from each side and a 5/16” hole in the center.
- Round the edges using a file or belt sander
- To assemble, put a 2” 5/16-18 bolt through the center hole of two steel plates. With a ball joint seated on either side of the bolt, add a wingnut to the other side of the bolt.

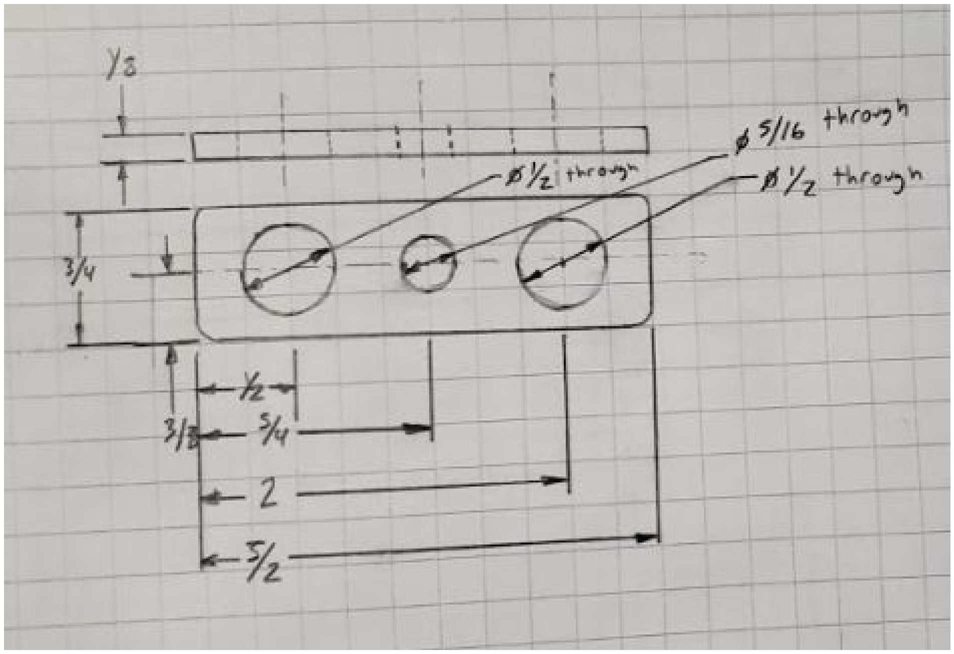

Figure 27: Ball Joint Plate

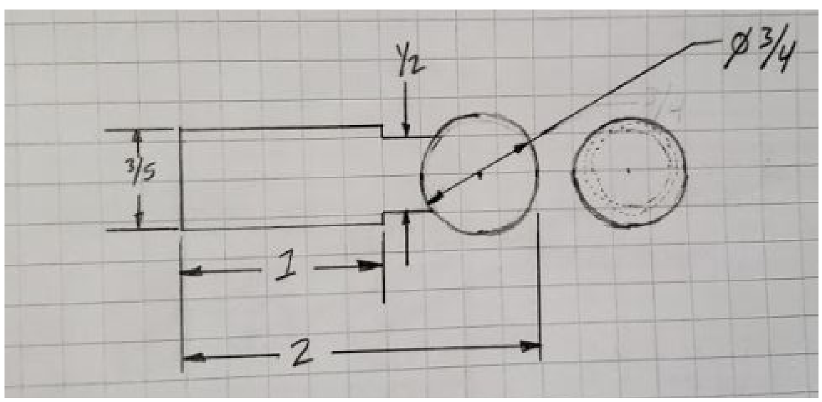

Figure 28: Ball Joint

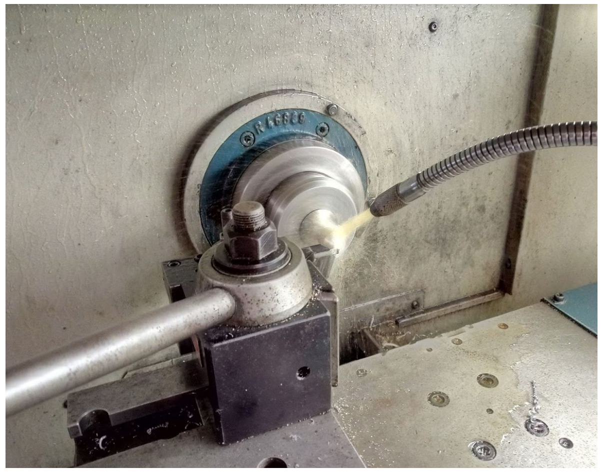

Figure 29: Machining a Ball Joint on the Programmable Lathe

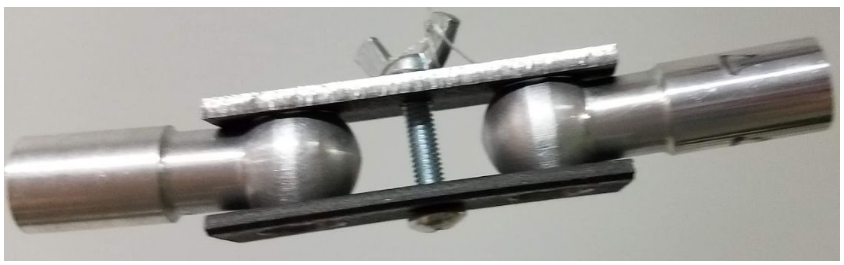

Figure 30: Ball Joint Assembly

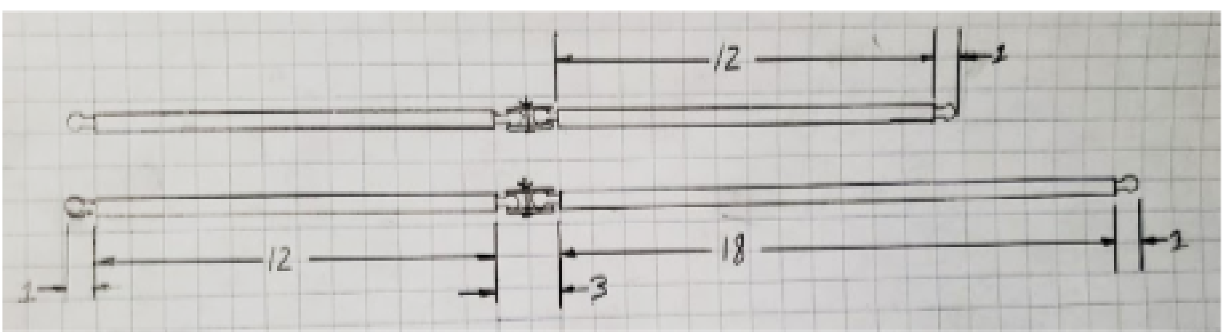

Figure 31: Arm Sub-Assembly

Constructing the Height Adjustment Mechanism

- Cut a 1” x 4” piece of aluminum on the bandsaw.
- Drill two number 10 holes in the center of the piece of aluminum, 1” from the top and bottom of the piece.
- In the center, drill and countersink a 5/16 hole.

- At the end of an aluminium ball joint, drill and tap a hole for a 5/16 - 18 bolt.
- Bolt the ball joint to the middle of the aluminium section.
- Cut 2 x ¾" by ¾" pieces of ⅛" steel using the bandsaw.
- Drill and tap a #10 - 32 hole in the center of both pieces of steel
- Thread a 1 ¼ bolt into both threaded holes, pass the bolts through the aluminium piece, then add wingnuts to each bolt.
- The completed height adjustment assembly should now slot into the aluminium channel.

Figure 32: Height Adjustment Mechanism

Constructing the Jelly Button Holder

- Cut a T shape out of the ¼" aluminium
- Drill and countersink a 5/16" hole in the center of the T shape
- On either side of the aluminium plate drill and tap a #10-32 hole.
- Cut 3 wedge shaped hooks and drill a #10 hole through the side.
- Bolt two of the wedge shaped hooks to the top of the aluminium T
- Using threadlocker, fix the bolt in the final hole and cut off the head of the bolt.
- Slide the last wedge shaped hook on the bolt and put a wingnut on the bolt adjust tension.
- At the end of an aluminium ball joint, drill and tap a hole for a 5/16 - 18 bolt.
- Bolt the ball joint to the middle of the aluminium section.

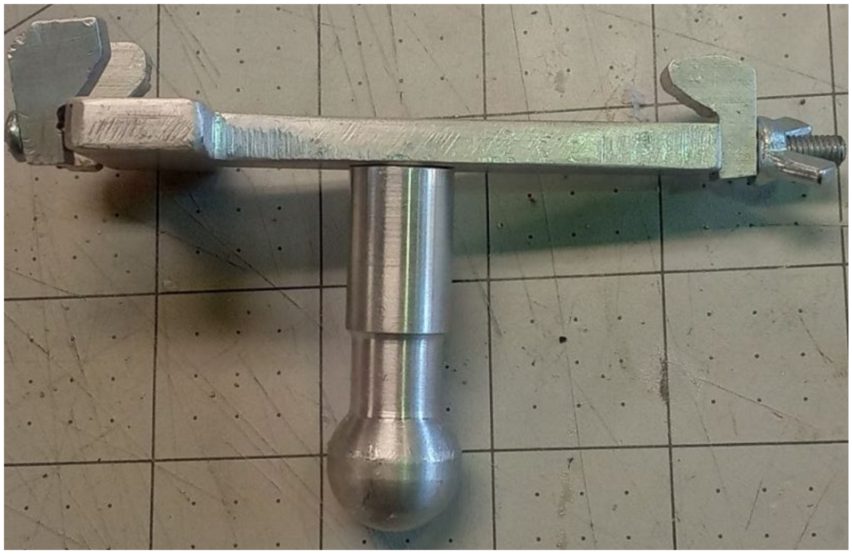
Figure 33: Jelly Button Holder Side View


Figure 34: Jelly Button Holder Top View


Figure 35: Wedge Shaped Hook Front View

Constructing the Microswitch Holder

- Cut a 1 ½” by 1” rectangle out of ¼” alumnium.
- Drill and tap a M1 hole on one side of the piece of aluminium
- Drive a M1 x 2 bolt into the threaded hole.
- At the end of an aluminium ball joint, drill and tap a hole for a 5/16 - 18 bolt.
- Bolt the ball joint to the middle of the aluminium section.

Figure 36: Microswitch Holder

Appendix K: Bill Of Materials

Prototype Expenses				
Description of Purchase	Qty	Vendor	Part Number	Cost
3/4 aluminum round stock	2	McMaster Carr	8974K11	10.59
Zinc-Plated Steel Wing Nut	1	McMaster Carr	90866A111	9.43
1/2 inch PVC pipe 10 ft	2	McMaster Carr	48925K11	4.36
Rubber casters	2	McMaster Carr	2406T24	3.82
Lock Washers	1	McMaster Carr	92147A031	6.37
Shop Materials Used				
Description	Qty	McMaster Carr	Part Number	Cost
3/4" by 1/8" flat stock	2 ft	McMaster Carr	8910K394	3.99
10-32 by 1.25" bolt	25	McMaster Carr	91735A841	4.35
1”x2” extruded aluminum channel	6ft	McMaster Carr	47065T107	30.39
2 ½” deck screws	25	McMaster Carr	90000A255	7.6
¼” Alumnium plate	6” by 6”	McMaster Carr	8975K71	9.07
M1 x 2 bolt	2	McMaster Carr	91800A057	7.46
⅝ -18 nut	25	McMaster Carr	95462A535	8.38
⅝ -18 2" bolt	10	McMaster Carr	92865A436	10.75
¼” Plastic sheet	6” by 6”	McMaster Carr	4296A162	4.82
Prototype Total				$140.15

Table 7: Bill of Materials