

Final Design Report: Attachable Arm Stabilizer

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Date:

March 9, 2024

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Executive Summary

Through collaboration with the Northern Suburban Special Recreation Association (NSSRA), we developed two customized supports for two power wheelchair users with cerebral palsy to increase their navigational independence. Both users can physically operate their power wheelchairs. However, they require assistance from NSSRA staff regarding everyday navigation.

We initially interviewed NSSRA Recreation Specialist, Mr. Joe Hart, to better understand our users, Dane and Rachel, and their issues controlling their power wheelchairs. Our interview was followed by a user observation that verified most of our interview information. We then built four different mockups that approached the issues from several angles and tested them with Dane and Rachel. From our testing results, we developed our final design concepts for Dane and Rachel and tested new customized mockups with them. Based on user feedback, we finalized our design and built the final prototypes.

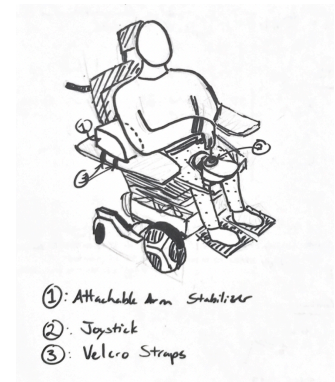


Figure 1: Dane's Wheelchair with Stabilizer

Our design, the Attachable Arm Stabilizer ('Stabilizer'), features two customized cushion tops that Dane and Rachel place their driving arm in front of or on top of when navigating, respectively. The Stabilizer additionally features two Velcro straps that allow for easy attachment to Dane and Rachel's current armrests. The Stabilizer was designed to meet three main requirements: User Independence, Accessibility & Ease of Use, and Durability & Maintenance.

- **User Independence:** The Stabilizer increases user independence through support supplied by the slants to the forearm and tricep of the user. The user can still freely move their wrist and hand while taking full advantage of the support provided by the Stabilizer.
- **Accessibility & Ease of Use:** The Velcro straps of the Stabilizer can be adjusted to fit around the width of the natural armrests. It can be installed by staff in less than a minute, and the users can utilize the Stabilizers without assistance from caretakers.
- **Durability & Maintenance:** Due to the fabric covering, the Stabilizer is usable in a variety of environments and it can be easily cleaned without damaging the fabric or cushion.

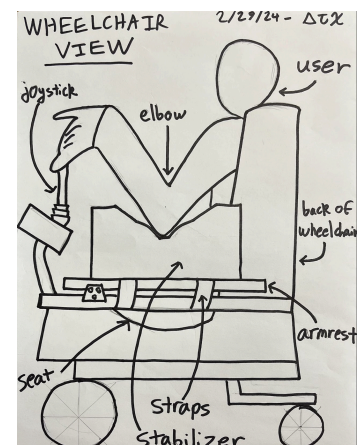


Figure 2: Rachel's Wheelchair with Stabilizer

Introduction

The Users

The Attachable Arm Stabilizer ('Stabilizer') was designed for Dane and Rachel, both of whom have cerebral palsy and are in their thirties. Dane and Rachel are participants at the Northern Suburban Special Recreation Association (NSSRA), located in Highland Park, IL. Dane and Rachel participate in daily activities at the facility and live with their parents. Both Dane and Rachel use Permobil 2019 F5 Corpus motorized wheelchairs (see Appendix B for more wheelchair info).

Dane & Rachel

Dane is in his mid-thirties and is nonverbal, but he can communicate through body language and facial expressions. Some of Dane's interests include superhero movies, video games, and Chicago White Sox baseball. Dane has a humorous personality and enjoys making jokes with the staff. He responds well to praise and encouragement.

Rachel is in her early thirties and can verbally communicate. She enjoys reading and is a fan of Chicago Cubs baseball. Rachel enjoys watching "The Price is Right" and creating art projects. Like Dane, she likes to tease and banter with the staff. Rachel is motivated by a desire for independence and autonomy, especially as it pertains to driving the wheelchair.

NSSRA Staff

Mr. Joe Hart was the initial client of the project and the primary contact for communication between the NSSRA and the DTC instructors. Mr. Hart worked as a recreation specialist at the NSSRA until his departure on February 16, 2024, and has known Dane and Rachel for several years. Since his departure, Ms. Becca Luecke, the recreation manager at the NSSRA, has been the client contact.

The project also incorporated feedback and interviews with members of the NSSRA staff. This includes caretakers who aided Dane and Rachel when they required assistance in steering their wheelchairs. Input was also taken from staff members who helped Dane and Rachel board buses to go on trips outside the NSSRA.

The Problem

Dane and Rachel experience difficulties in steering their motorized wheelchairs and are sometimes unable to make fine motor movements with the joystick. As a result, they often crash into the walls at the NSSRA facility, which causes damage and dents (*Figure 1*). Navigation also requires assistance from the staff, who are called to help Dane and Rachel steer away from the wall after crashes.



Figure 3: Dents and wall damage caused by wheelchair crashes

Crashes often occur at corners because Dane and Rachel experience difficulty in making sharp turns. Driving through tight or narrow spaces is also challenging. This has been especially apparent when boarding elevators. According to Mr. Hart, the elevator doors sometimes close on Dane and Rachel's wheelchairs as they are boarding (Appendix C). When this happens, staff are called to hold the elevator doors open and help Dane and Rachel board the elevator.

To address these problems, the NSSRA staff created an obstacle course using half-cones (Appendix C). These cones were arranged as two borders so that Dane and Rachel could drive through the center of the path. Dane and Rachel would attempt to drive between the cones without hitting them. However, the obstacle course created by the NSSRA has been largely unsuccessful.

According to Mr. Hart, Dane and Rachel have viewed the obstacle course more as a game than as a learning experience. For example, they make jokes about crashing and view the experience as humorous. Furthermore, because the cones are below waist level, Dane and Rachel are often not able to see them. As a result, their crashes often occur foremost because of limited visibility, rather than an inability to control the wheelchair.

There are several reasons why addressing this problem is important to Dane, Rachel, and the NSSRA staff. First, the physical damage caused to the walls will require repairs. By helping Dane and Rachel steer their wheelchairs more comfortably, the number of crashes could decrease, meaning that the NSSRA will not have to repair as much damage.

Furthermore, helping Dane and Rachel avoid crashes will increase their independence and autonomy. Currently, when they crash into walls or elevator doors, NSSRA caretakers are called to help them steer their wheelchairs. Dane and Rachel both strive for independence and are looking for a solution that enables them to require less assistance from staff.

Project Requirements

User Independence

The driving force behind the development of the Attachable Arm Stabilizer is the increase in Dane and Rachel's independence. The final prototype should, above all else, give Dane and Rachel confidence and increased control of their maneuvering abilities, while also lightening the workload of NSSRA staff. The end users deserve to have as much mobile autonomy as possible, and the prototype should help achieve this goal. To achieve this, the NSSRA staff must perceive a noticeable difference in Dane and Rachel's driving abilities when using the Stabilizers. This will be measured by a 2 or greater on a scale of 0 to 5, where 0 is no change or worsening control, and 5 is a completely new degree of independence and control of the power wheelchairs.

Accessibility & Ease of Use

The project must have approval from both Dane and Rachel. The Stabilizer must be compatible with the dimensions of Dane and Rachel's wheelchairs, and it must be able to fit around the width of the natural wheelchair armrest (Appendix A). It must take less than a minute for NSSRA staff to install and set up, to ensure that the solution is efficient and saves time. It must also take less than a minute to detach the Stabilizer from the wheelchair. Furthermore, Dane and Rachel must be able to place their arm or elbow on the Stabilizer without assistance. While staff may be necessary to install the prototype, Dane and Rachel must be able to make use of it without staff assistance. This is essential to promoting Dane and Rachel's sense of independence. Additionally, the Stabilizer must be able to be detached should Dane and Rachel want extra free space.

Durability & Maintenance

Because Dane and Rachel participate in outdoor activities, the project must be usable in a variety of environments. It must be able to endure being doused with water and must be functional in a range of temperatures common to the Chicago area (-10 to 100 degrees Fahrenheit). To ensure its use over long periods, staff must be able to clean the product without damaging or rendering it unusable, so the fabric must be compatible with standard cleaning wipes. In addition, because the Stabilizer is designed to support the weight of Dane and Rachel's arms or elbows, it must be able to withstand 40 pounds of force.

Other Requirements

Other basic comforts identified as requirements for the final prototype include the physical effect of the prototype and its overall sensory appeal. In regards to the physical effect of the solution, the product aims to eliminate all unnecessary motion of the users' arms, so there must not be any space between the product and the arm/elbow of the user. Regarding sensory appeal, along with being visually appealing, the materials used should be comfortable enough for Dane and Rachel to use for extended periods without chafing, skin irritation, or other complaints. On a scale of 1 to 10, Dane and Rachel must rate the comfort levels of their Stabilizers as 7 or above, with 10 being extremely comfortable and 1 being bothersome.

Report Outline

This report will describe the concept that was pursued, and how this concept led to the creation of the Stabilizer. It will outline how the product addresses the users' challenge, and what it does to increase Dane and Rachel's autonomy. Furthermore, the report will elaborate on potential future concepts that another team could pursue with the prototype. Appendices can be found at the end of the report, including the project definition (Appendix A).

Design Concept and Rationale



Figure 4: Dane's Stabilizer Design



Figure 5: Rachel's Stabilizer Design

The Attachable Arm Stabilizer (*Figures 4 & 5*) is a device that provides support for Dane and Rachel, a man and woman (no familial relationship) with cerebral palsy, allowing them to maximize control of their power wheelchairs when driving. The Stabilizer has a cushioned top for them to rest their elbow or arm on when the device is in use. The difference in designs comes from user testing where Dane and Rachel express needs for different types of support: Rachel for her elbow and Dane for his tricep (Appendix D).

Rachel's variation of the Stabilizer has two slanted surfaces, on the front and back of the device, which cradles the forearm and tricep of Rachel, providing both vertical and horizontal support to Rachel's elbow. (*Figure 6*).

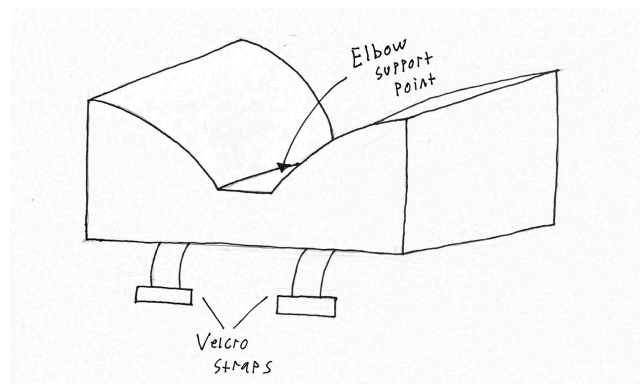


Figure 6: Isometric View - Rachel

The second variation is designed so that the top of the Stabilizer is a single slant supporting only the tricep of Dane, preventing any sliding of his elbow backward toward the stomach (*Figure 7*).

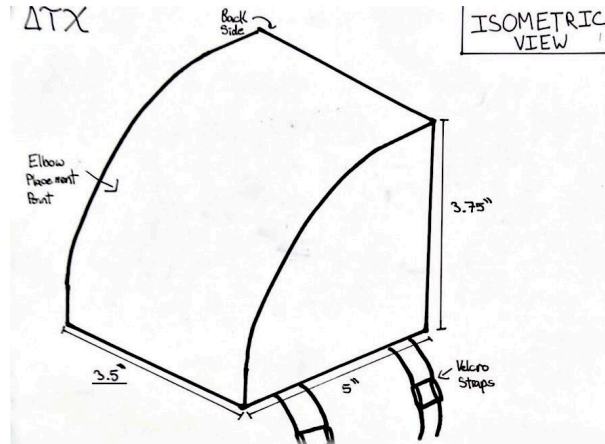


Figure 7: Isometric View - Dane

The following sections describe the components of the Stabilizer (both variations)—slants, cushion, and cover—as well as the rationale for each component based on research and user testing.

Slants

Specifications and Use (Rachel's Two-Slant Design)

Both slants are 2" x 3.5" and are separated by a 0.125" space where Rachel rests her elbow (*Figure 8*). When Rachel wants to navigate to another location (for example), she lifts her arm and places her elbow squarely between the two slants, resting her forearm on the front slant, and her tricep on the back slant. Now that she has more support for her elbow, Rachel can take hold of her joystick and maneuver where she needs to go in a controlled and supported manner.

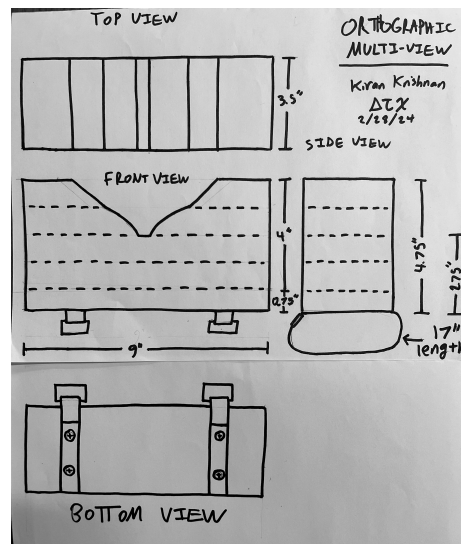


Figure 8: Orthographic Multiview - Rachel

Rationale (Rachel's Two-Slant Design)

The two slants allow Rachel's arm to be fully supported by the Stabilizer without any additional stress or assistance required by the rest of her body while still supplying a full range of motion to her wrist and hand. User observation showed a significant gap (3") between Rachel's elbow and the natural armrest of her power wheelchair which caused some discomfort and lack of control (Appendix E). In addition, user testing with the initial mockups showed that Rachel greatly appreciated the added support but wanted a design that would better cradle her arm (*Figure 9*).

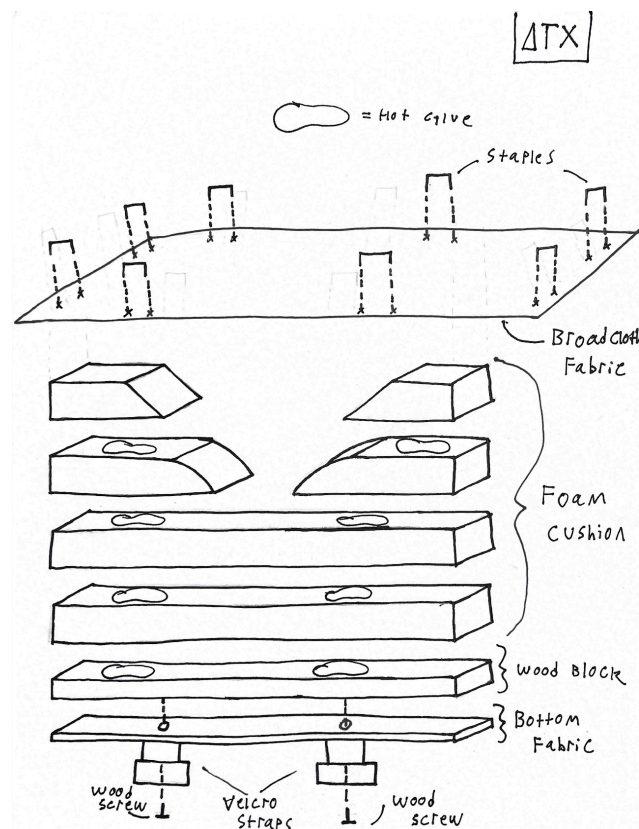


Figure 9: Exploded View - Rachel

From this information, it was determined that the final Stabilizer design should include slight inclines to support Rachel's arm so she can take greater advantage of the added vertical support without any unnecessary strain or discomfort in the horizontal direction. When using the final Stabilizer design, Rachel stated that she felt more supported and more in control of her wheelchair. Rachel's increased control with the Stabilizer should result in less navigational assistance needed from staff attendants, thereby increasing Rachel's independence when navigating her wheelchair. While Rachel was able to verbally confirm her increased comfort and

control when using the Stabilizer, verification from Staff members regarding a decrease (or increase) of assistance required on their part has yet to be confirmed.

The flat space between the slants is so that Rachel can easily lift her arm and place her elbow between the slants without the need for staff assistance, which she was able to do with the mockup featuring the slant design (*Figure 9*). Also, the 3.5” width of the Stabilizer was to accommodate the natural armrest without unnecessary overhang but still have enough surface area to fully support the front and back of the user’s arm (Appendix E).

Specifications and Use (Single-Slant Design)

The top of the device slants towards the front with a rounded edge (*Figure 7*). The height of the slant is 3” and the width is 3.5”. Dane rests his tricep on the slant, placing his elbow in line with the base of the support on the natural armrest of his wheelchair.

Rationale (Single-Slant Design)

The slant allows Dane to rest the device comfortably beneath his tricep, rather than his elbow, while preventing his arm from sliding backward. Compared to the first iteration, this steeper angle was determined from user testing (with mockups). Dane struggled to have the original mockup underneath his elbow due to the height of the mockup. However, he did reiterate that support of his arm from behind when his arm is in the driving position would be appreciated. Therefore, the final design incorporates a single slant that supports the arm from behind and allows Dane’s elbow to rest on the natural armrest where it is most comfortable.

Cushion

Specifications and Use

The inside cushioning of the Stabilizer consists of a polyurethane foam that has been cut to have the same slant features mentioned above. The compression pressure is 1.1 psi for 25% compression. Dane and Rachel will rest the entirety of their arm weight onto the slanted parts of the foam, with Rachel’s elbow placed on the flat 0.5” section of the two-slant design and Dane’s elbow resting on the natural armrest of his wheelchair (level with the base of the Stabilizer).

Rationale

The polyurethane foam is machinable, supportive, and comfortable, allowing Rachel to rest her elbow comfortably while having a cut shape that is more form-fitting to the positioning of her arm. From user testing, Rachel revealed that she needs more comfortable cushioning for her

Stabilizer design and wants her arm to be more cradled. Therefore, the final design incorporates a material that can attend to both Rachel's needs for comfort and multidimensional support (Appendix A).

Cover

Specifications and Use

The covering material is a broadcloth sheet that wraps around the entire top part of the Stabilizer and fastens to the underside of the upper wood base via staples (*Figure 10*). The broadcloth is cleanable and does not irritate the skin of the user while still preventing the user's arm from slipping on the material.

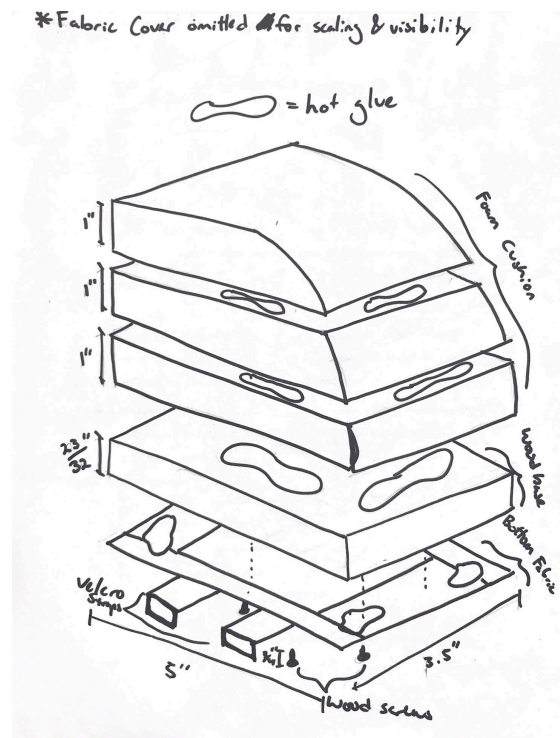


Figure 10: Exploded View - Dane

Rationale

The broadcloth is cleanable so that should it become dirty, the NSSRA staff can easily wipe it down with a Clorox wipe without a major inconvenience for Dane or Rachel. The ideal material could easily withstand those cleaning agents so as not to inconvenience the NSSRA staff and to ensure that the surface of the Stabilizer continues to be appealing to Dane and Rachel for a long period of time.

Velcro Fasteners

Specifications and Use

The mechanism for both Dane and Rachel's Stabilizers is composed of two nylon Velcro straps with rectangular metal loops (*Figure 9*). The straps are 1" wide, and each strap is cut from a single long strip. One region near the end of each strap is stapled to the base wood of the Stabilizer, looped under the natural armrest of the power wheelchair, fed through the metal loop, and fastened to itself. This routing of the strap will be done by NSSRA staff whenever the product is attached or detached from the wheelchair.

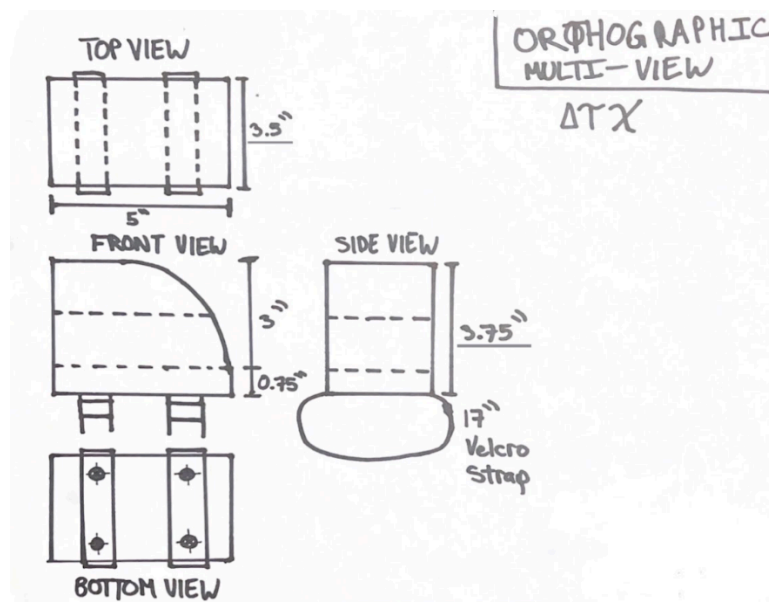


Figure 11: Orthographic Multiview - Dane

Rationale

Velcro was chosen for its user-friendliness, ability to function in a variety of environments, and price. It is toolless and quick to use, such that NSSRA staff do not have to worry about any hassle in setting up the Stabilizer. The learning process of learning how to attach and remove the Stabilizer will consequently be short.

Future Development

User Testing

The two final Stabilizer prototypes were designed around two specific individuals, both living with the same condition (cerebral palsy). Due to the unique nature of each prototype and its ability to comfortably fit the client's arm, it is unlikely that these exact prototypes will function to a satisfactory level for other individuals with challenges similar to those of the clients. However, following proper matching of subsequent Stabilizer geometries with the arm positions of possible future users, there is promise that this solution will work for power wheelchair users with other neuromuscular disorders, such as those with amyotrophic lateral sclerosis (ALS). Put briefly, future testing could be done after developing similar prototypes for individuals with other disabilities than just cerebral palsy.

Performance Testing

Testing for this prototype was only done using short-term challenges to the waterproofing and anti-wear nature of the materials chosen. Prolonged exposure to exceptionally hot, cold, or rainy environments should be tested to ensure the steady function of the prototype in all climates. To gauge how long the Stabilizer may be used before experiencing excessive wear to its outside fabric, friction testing should also be conducted. This could guarantee that users or their caregivers need not frequently worry about replacing the fabric of the Stabilizer.

Material Selection

A total of three different fabrics were tested during the development of this prototype. Other fabrics than just those tested may work for the climate-proofing necessary for the solution, potentially with cost, cleanability, and aesthetic benefits as well. More fabrics including faux leather, polyester, and cotton-based solutions should be tested. While the current fabrics used in the Stabilizers are slightly water-resistant, fully waterproof options should be considered.

Three different foams were also tested for the cushioning aspect of the Stabilizer. Foams developed for use in the mattress insole, and carpentry industries could all be worth testing for rigidity, flexibility, and overall comfort. However, because the comfortable use of the Stabilizer is so individualized, users should be individually consulted before making any changes to the foam selection for the cushion.

Fabrication

Potential lies in the optimization of the fabrication techniques for the building of the Attachable Arm Stabilizers (see Appendix F for full instructions for construction). For example, if the cushions were cut from a single, thick sheet of foam, rather than being made by stacking several thinner, 1” layers, misalignment and layer separation could be mitigated. It would also be ideal for the fabric cover to be removable for washing, while still holding tightly onto the body of the Stabilizer when in use.

Custom Sculpting

One promising step towards successful customization of the Stabilizer is a digital or analog measurement of the exact arm geometry of the user. Using technology like LiDAR sensors or a shape-holding mold around the arm of the user, a cushion shape that exactly matches the shape of the end user could be developed. This would allow for more precise control of the shape of the Stabilizer, and increased comfort for the user, one of the goals of this project. This is especially promising, given that Dane requested that his Stabilizer eventually assume a shape with a divot in the front to cradle his arm.

Conclusion

Overall, the Attachable Arm Stabilizer design offers both Dane and Rachel a comfortable arm support system on their wheelchairs, providing a simple and effective solution to their navigation difficulties by making the process of using the joystick more comfortable for them both. Such support reduces the concentration required for Dane and Rachel to control their movement, thereby improving their control of their wheelchairs and improving overall autonomy in the process.

Dane and Rachel need a product that adds comfortable assistance for Dane and Rachel as they drive their motorized wheelchairs which does not interfere with any of their other day-to-day activities. They also need a design that is easily cleanable and can withstand the elements that come with Illinois' climate – the chosen fabric and attachment mechanism meet those requirements.

Regarding said attachment mechanism, it meets the NSSRA staff's need for the design to be easily removed and attached to their wheelchairs. Staff can intuitively attach and remove them from the wheelchair within a minute; engaging and disengaging the model within 10 seconds (see Appendix G for full process of use).

Beyond meeting all of Dane, Rachel, and the NSSRA staff requirements, the design functions per all limitations. The Stabilizer was produced comfortably under the full \$150 budget (see Appendix H for all materials used) and was delivered on schedule.

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Appendix A: Project Definition

Project Name: Attachable Arm Stabilizer ('Stabilizer')

Client: Northern Suburban Special Recreation Association (NSSRA); Dane, Rachel

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Date: March 9, 2024

Mission Statement: To design an attachment for the armrest of Dane and Rachel's wheelchairs that comfortably maximizes the control of their power wheelchairs when driving, minimizes crashes, and aids in making sharp turns and navigating tight spaces.

Project Deliverables:

- Project Report
- Poster/Presentation
- Final Prototype
- Design Sketches for the Final Prototype
- Design Summary

Constraints

- Budget: \$100 + \$50 shipping
- Compatible with Permobil 2019 F5 Corpus wheelchair used by Dane and Rachel

Users/Stakeholders

- Dane and Rachel
- Other motorized wheelchair users and Dane and Rachel's families
- Caretakers/staff at the NSSRA
- People with cerebral palsy or any other conditions which impact motor control

Table 1: Project Requirements and Specifications

Category	Requirements	Specifications
<i>User Independence</i>	Must decrease user reliance on NSSRA staff for navigation	NSSRA staff rank perceived improvement to control as ≥ 2 on a 5-point scale

<i>Physical Effect</i>	Must prevent elbow and/or forearm from hovering	No measurable space between Dane or Rachel's elbow and Stabilizer
<i>Accessibility</i>	Must be able to fit on Dane and Rachel's wheelchairs	Must be able to fit around the width of built-in wheelchair armrest (4" width)
	Must require little time to install	Staff should be able to install the Attachable Arm Stabilizer in less than a minute
<i>Ease of Use</i>	Must be easy for Dane and Rachel to use without assistance from others	Dane and Rachel must be able to place their arms on the Stabilizer without staff assistance
<i>Maintenance/Durability</i>	Must be able to resist light amounts of force from elbow and/or forearm	Must be able to resist 40 lbs of weight placed directly on top.
	Must be protected from liquids such as juice and water	Must be able to endure dousing with 500mL of water.
	Must be able to be used in a variety of environments, including outdoors	Must be usable in temperatures ranging from -10 to 100 degrees F
	Must be able to be easily cleaned	No chemical impact of cleaning products (Clorox wipes)
<i>Appeal</i>	Top of the Stabilizer must use a soft material that is comfortable for Dane and Rachel	End user rates comfort level at $\geq 7/10$

User Profiles

Dane is a man in his mid-thirties with cerebral palsy. He uses a Permobil 2019 F5 Corpus motorized wheelchair. Dane attends the NSSRA and enjoys watching movies and video games. He is also a sports fan, especially the White Sox. Dane has a humorous personality and enjoys

bantering with people and making jokes. Dane communicates nonverbally through facial expressions and responds well to praise and affirmation.

Rachel is a woman in her early thirties. She also has cerebral palsy and uses the same type of wheelchair as Dane. Rachel enjoys reading and is a fan of baseball, especially the Chicago Cubs. She likes to be intellectually stimulated by activities such as art projects, and game shows such as “The Price is Right”. Rachel communicates verbally and is very clear about what she enjoys and what she dislikes. She is driven by a desire for personal independence and autonomy.

Illustrative User Scenario

The user in the following scenario is based on observations of Dane and Rachel, both of whom have cerebral palsy and use motorized wheelchairs. Information from Mr. Joe Hart also contributed to the understanding of the problem.

Rachel arrives at the NSSRA in the morning to participate in the daily activities offered at the building. Rachel has cerebral palsy and uses a motorized wheelchair. During the day, she watches “The Price is Right” and creates art projects with the help of the staff. However, when she is driving through the halls, she crashes into a corner and dents the wall. She laughs at this, but she does not enjoy having to receive help from the NSSRA caretakers.

To help improve her driving, Mr. Hart and the other staff have set up a casual obstacle course with cones. Rachel participates in the course, but she isn’t able to see the cones and sometimes drives over them. Rachel and the staff make jokes about the incident, but Rachel wishes she was able to make more precise movements with the wheelchair: especially when making turns and navigating around corners. Rachel yearns to be more independent in driving the wheelchair, and receiving assistance from the caretakers diminishes her independence.

Appendix B: Secondary Research Summary

During the first week of the project, research was compiled regarding the aspects and range of the project description provided by the primary client, NSSRA recreation specialist, Joe Hart. Mr. Hart requested a solution aimed at helping 2 of his adult day program participants, Dane and Rachel, learn to navigate and control their joystick-operated power wheelchairs. The end goal is to provide more independence for Dane and Rachel and remove some attendance responsibilities from both NSSRA staff and both participants' families. Initial research commenced to provide useful insights into the following aspects of the project:

- The mission of the NSSRA, as well as other similar organizations
- Scope of power wheelchair navigation troubles as a whole
- Wheelchair user demographics, and basic information into types of wheelchairs
- Existing solutions for similar problems

With this research, more meaningful questions could be generated to ask during the first interview with the client.

NSSRA Background

Established in 1970, the Northern Suburban Special Recreation Association (NSSRA) is recognized as the first special recreation association in the country, and it provides an array of services for people with disabilities across Chicago's northern suburbs covering ten park districts, two cities, and one village. The NSSRA offers over 700 cultural, sport, social, physical, outdoor, trip, and special event programs year-round run by dedicated, trained staff that serve more than 5,000 registrants of all age groups annually [1]. These programs are designed to accommodate participants with almost any disabilities – mental or physical. As such, they have directly contributed to enhancing the communities of northern Chicago by enhancing all aspects of the lives of participants. Specifically, the NSSRA's mission is to “enrich the lives of people with disabilities in our[its] partner communities through quality recreation services.” benefitting participants through “improvement of cognitive and fine/gross motor skills,” amongst a host of other contributions [1].

Other Organizations

Another member organization of the Special Recreation Association Network of Illinois is the Special Recreation Association of Central Lake County (SRACLC) [16] which was established in 1976 [18]. Similarly to the NSSRA, SRACLC serves its community by providing recreation programs and services to individuals with special needs or disabilities, and their families, who reside within the boundaries of Member Agency communities [18]. It serves essentially the same function as the NSSRA, instead for residents in and around Lake County. SRACLC offers dedicated facilities and programs to enhance the awareness and senses of program residents. Its Sensory Programs and Sensory Rooms have acted as helpful tools in facilitating sense development for participants.

Scale of the Problem

The broad issue of control and navigation of power wheelchairs is very common for people with disabilities. It was found that a very large number of people with “neuromuscular disorders or reflex disabilities” (i.e., cerebral palsy) have extreme difficulty operating a power wheelchair, specifically power wheelchairs with joystick control [5]. Many articles have covered research on assistive technologies such as gestural control [15], “visual servoing” [6], and other more elaborate solutions aimed at driving user independence. While these articles do emphasize the commonality of power wheelchair navigation problems, the focus is mostly centered on technological advancement rather than user training. One article proposed a method of limiting the speed or sensitivity of the vehicle to facilitate more control for the use, but after evaluating a user survey, the researchers learned that it was not helpful. Power wheelchair users stated that “this [method] was a very serious intervention that had implications for themselves and others” [17].

Wheelchair User Demographics

People who use wheelchairs and other mobility devices are required to do so due to a myriad of reasons. Manual wheelchairs, power wheelchairs, segways, and other power-driven mobility devices (OPDMDs) serve people depending on their needs and symptoms of disability [2]. Physical disabilities that require wheelchair use can be sorted into two categories: orthopedic disabilities and neuromuscular disabilities [14], though no single type of wheelchair “fits” either category perfectly—determining the ideal mobility aid is much more complex than that. Those who select manual wheelchairs may have been diagnosed with spina bifida, had an amputation, live with paraplegia, or just want to maintain their upper body strength while living with another disability [14],[2]. Similarly, a range of orthopedic and neuromuscular disabilities require the use of a power wheelchair [14]. These power wheelchair users are unified by the fact that they, on average, travel significantly further per day than their manual wheelchair-using counterparts [19].

Power wheelchair users have a median age of about 57 years old [9]. It is also important to note that the use of wheelchairs takes place at a disproportionately high rate among people from lower socioeconomic backgrounds [11].

Existing Solutions

Wheelchair obstacle courses have been made in the past and can serve multiple purposes. One example is for recreational or athletic activities. In August 2016, designers built a temporary obstacle course in New York City, which was intended for wheelchair users, non-wheelchair users, and people with prosthetics [4]. These designers aimed to build a course that could be used by everyone. Obstacle courses have also been used for medical purposes. A 1989 article from the *Journal of Clinical and Experimental Neuropsychology* described how researchers used an obstacle course to assess motor difficulties for right cerebral accident victims. The obstacle course featured three left turns and three right turns, with gray folding chairs in the middle serving as obstacles to avoid [8]. Researchers observed if the number of collisions was correlated with the participants' hemispatial neglect, which was caused by their strokes. There are also technological solutions that have been made for the wheelchairs themselves. The company Braze Mobility produces blind spot sensors for wheelchairs. These sensors help the users spot objects behind the wheelchair, similar to a rear-view mirror on a camera [3]. Furthermore, researchers at the 2018 IEEE International Conference on Systems, Man, and Cybernetics presented a haptic guidance system for wheelchair users. If objects are detected in the wheelchair's path, the system will send a force through the joystick, warning the user about the obstacle [10].

Appendix C: Project Partner Interview Summary

Introduction

The purpose of this interview was to gain a deeper understanding of the nature of the design challenge, as well as generally establishing a line of communication with the project partner. Given how early it is in the design process, this interview was paramount to an accurate start to the design process.

Methodology

At about 11:30 am on Tuesday, January 9, 2024, project partner and NSSRA Recreation Specialist Mr. Joe Hart joined via Zoom after kindly agreeing to an interview. The format of the interview involved Mr. Hart briefly introducing himself and his role at the NSSRA to the interviewers (the students and professors). For the rest of the interview, each team was allotted an amount of time to address Mr. Hart without interruption. Once all teams had their chance, the floor was opened up to a free-form Q&A session.

Results

The People

As Recreation Specialist, Mr. Hart oversaw the NSSRA adult day program, which provides fitness, recreation, and art activities to its customers daily. The goals of the program also include helping its participants develop basic independent skills, like laundry, washing dishes, etc. While Mr. Hart was overall a staunch supporter of the use of power wheelchairs, he acknowledged that there are usually a few “accidents” per day at the NSSRA, usually involving bumping into walls, scratching the walls of elevators, making excessively wide turns or general trouble moving from room to room.

The two participants at the center of the project, Dane and Rachel, are both in their thirties, living with their parents, and living with cerebral palsy. Each of them has been using their current wheelchairs for several years; the specific model of the wheelchair in question is driven by a right-hand joystick, the interface of which also includes some kind of button mechanism that controls the speed mode of the chair. The sensitivity of the controls of the wheelchair was a point of concern to Mr. Hart, a problem only exacerbated by the fine motor troubles of Dane and Rachel that only allow them to “punch” the joystick whenever they are attempting to make fine adjustments during navigation.

Framing the Problem

Mr. Hart was very clear in his belief that the problem lies not in the power wheelchairs, but in Dane and Rachel's respective abilities to use them. The current solution, a hastily thrown-together obstacle course at the NSSRA, has turned into more of a game than a solution; Dane especially enjoys crashing into the obstacles as a kind of game.

Many of Dane and Rachel's similarities come from their condition. Each of them has a decent range of mobility but is generally stiff in their movements— "rigid," to quote Mr. Hart. This results in difficulty fully straightening their arms and limited or delayed hand-eye coordination. They can each grip small objects like pens, though the careful use of them is a challenge; activities like drawing or others that require fine motor skills always require a fair amount of assistance from the NSSRA staff.

Personality-wise, they share a great sense of humor and an undeniable ability to read people. They both have an impressive attitude and work ethic in regards to becoming more independent, appreciate explanation and inclusion of whatever is going on around them, and perhaps above all, absolutely despise not being treated as the adults they are. However, that's about where their similarities end. Dane is a known sports fan, including participating in them, but also loves superheroes, watching people play video games and movies, and hearing a good (or bad) joke. Rachel is less into physical activities, likely because the things she loves most allow her to be truly independent. She's highly communicative in both body language and speech (Dane is non-verbal, though also communicates well through gestures) and loves stories, art projects, and "The Price is Right."

Final Solution

In regards to what Mr. Hart wanted the final product of this design process to look like, he also provided great insight. Firstly, he mentioned that it would be "huge" for the solution to be easily set up and removed by NSSRA staff. He also mentioned that Dane and Rachel would surely love it if they could in some way accessorize the solution. Functionally, anything that allowed them to better make turns, be loaded onto the bus, and make navigation a more independent process for both Dane and Rachel is welcome. He also included that the project should be durable and functional indoors and outdoors to accommodate the range of activities provided by the NSSRA.

Discussion

Guiding Principles for Final Design

The main focus in designing the solution will be to address all of Mr. Hart's concerns regarding product specifications. The topic of independence was a recurring one in the interview, so the ideal solution will also try to remove as much of the workload from NSSRA staff as possible when helping Dane and Rachel navigate, especially in situations like loading and unloading participants onto the bus for trips. Some points of focus for the design, as guided by this interview, will include the joystick mechanism currently used by Dane, Rachel, and millions of other power wheelchair users.

Early Ideas

While one solution should work for both Dane and Rachel (their challenges seem nearly identical), their respective personalities should be in mind for ways that each of them can personalize their solution, whatever that ends up looking like. Learning from the shortcomings of the obstacle course, we'll also keep in mind the idea of the solution being a kind of learning game for whoever ends up using it. Plans for the near future include reviewing a video sent by Mr. Hart of Dane and Rachel's navigation struggles in action, as well as noting any other questions that were potentially missed during the virtual interview and sending them to the NSSRA through the proxy of Prof. Hoffmann.

Appendix D: Mockup Testing and Feedback Summary

Introduction

Initial user testing and feedback occurred over 2 visits to the NSSRA on February 1st & 8th, 2024. During the first trip, Dane and Rachel were consulted in the common area to discuss their preferences and initial reactions to the 4 mockup ideas. While it was impossible to test the mockups with Dane and Rachel, they could be explicitly described to them for their immediate feedback. Their responses then prompted the focus to be narrowed down to creating support for Dane and Rachel's arms. A new series of arm support mockups was generated in preparation for the second round of user testing.

Methodology (i)

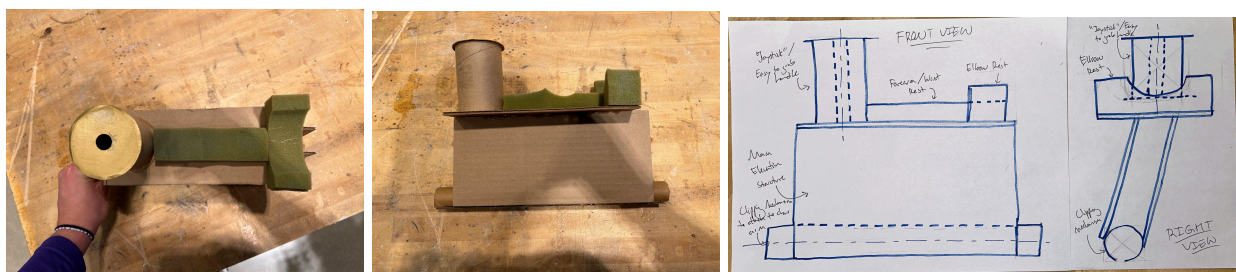
The 4 initial mockup ideas tested (displayed below) were an Arm Stabilizer, a Mirror/Camera Extension, a Joystick Attachment, and a Baseball-themed Obstacle Course. The goal for each mockup was to pursue a different avenue toward solving the overarching problem, helping Dane and Rachel become better power wheelchair drivers.

Attachable Arm Stabilizer

Solution Avenue: Arm Support

Questions Asked to Dane and Rachel:

- Have you had support for your arm before?
- Is it uncomfortable for you to have your arm unsupported?
- Would you be interested in having some support for your arm?

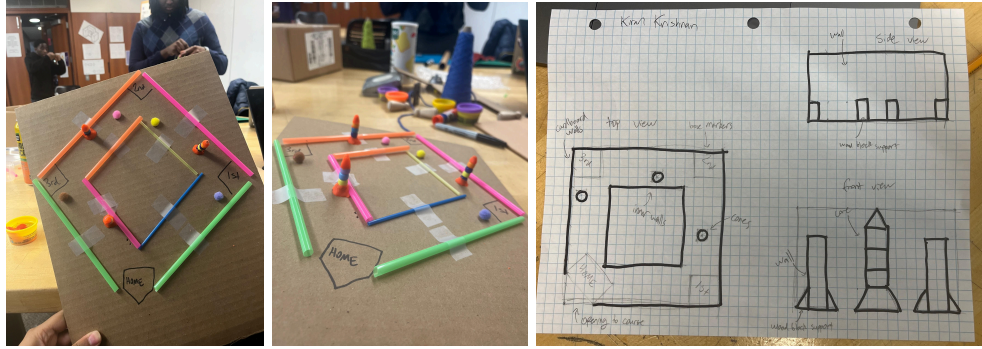


Figures 12-14: Original Stabilizer Mockup

Mirror/Camera Extension

Solution Avenue: Expanding Visual Field

Questions Asked to Dane and Rachel:



Figures 20-22: Baseball-Themed Obstacle Course

Methodology (ii)

The second visit involved a combination of physically testing built mockups with Dane and Rachel and showing Dane and Rachel design sketches of additional mockup ideas to get their feedback. Having focused on a particular area of contention since the first user testing, a variety of different mockup ideas were presented and lots of useful information (that will be covered in the next section) was gained. The first main goal of this visit was to obtain solid measurements of Dane and Rachel's power wheelchairs as illustrated in Table 1 below.

Table 2: Natural Armrest Measurements for Dane and Rachel

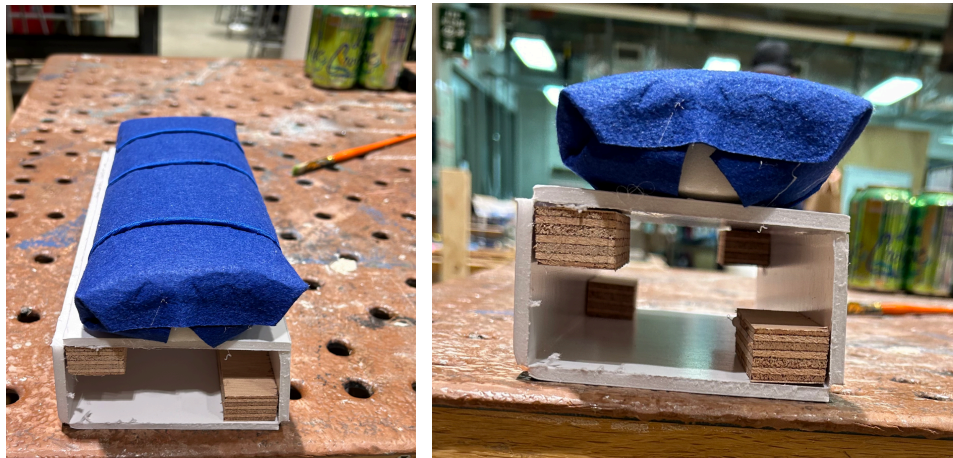
Dane		Rachel	
Armrest Length	13 in.	Armrest Length	13 in.
Armrest Height	1.25 in.	Rod to top of Rest	3 in.
Armrest Width	4 in.	Armrest Width	4 in.
Joystick Height (from base)	5.5 in.	Joystick Height	7 in.
Elbow to Joystick	13 in.	Elbow to Armrest (while driving)	3 in.
Wrist to Joystick	7.5 in.		
Armrest to Bottom Bar	2.75 in.	Armrest to Bottom Bar	5 in.
Bottom Bar Length	7 in.		
Front of the	4 in.	Front of the armrest to	1 in.

armrest to Joystick		Joystick	
Back of the armrest to Joystick	17 in.	Back of the armrest to Joystick	5 in.
Joystick Diameter	0.5 in.	Joystick Diameter	1 in.

Another second main goal was to have Dane and Rachel, with their permission, test the built mockups and provide feedback on the sketches and ideals of the others. the ideas included variations on the original Stabilizer outlined above along with 3 other sketches that depicted other ways of supporting Dane and Rachel's arms, a joystick attachment that provides 360° resistance increasing control of movements with the joystick, and a camera and wireless display system that would expand the field of view for Dane and Rachel to ground level. This last mockup idea has not been officially tested at this time and in the interest of sticking to relevant information, this mockup idea will not be discussed in this summary.

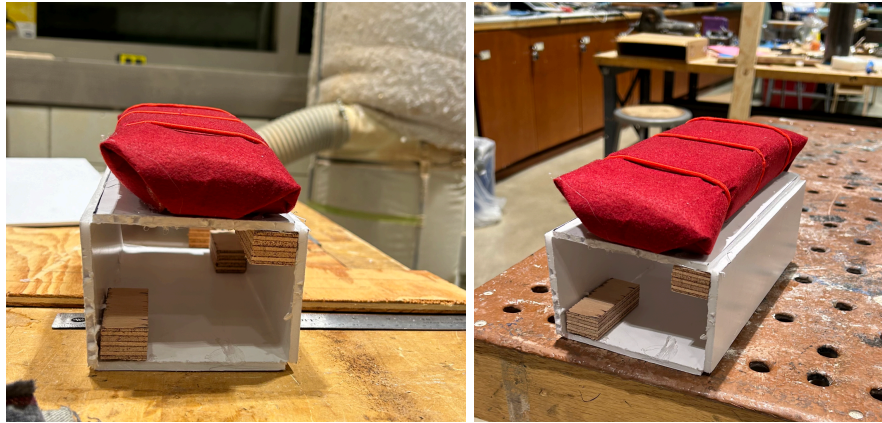
Attachable Arm Stabilizer Variations - 2 Sizes (See Below)

Size 1: (10 in. x 4 in. x 2 in.)



Figures 23-24: Stabilizer Mockup 2 (Blue)

Size 2: (8 in. x 6 in. x 3 in.)



Figures 25-26: Stabilizer Mockup 2 (Red)

For the testing of this mockup, Dane and Rachel were asked for permission to try the elbow rest with them and to have them drive around with them. Both sizes were successfully tested with Rache, however, Dane was unable to test them for reasons that will be discussed in the results section. Rachel placed the Stabilizers under her elbow and navigated around with them, simultaneously providing feedback. Questions were posed regarding the comfortability, helpfulness, and positioning of the Stabilizer.

C-Shaped Support

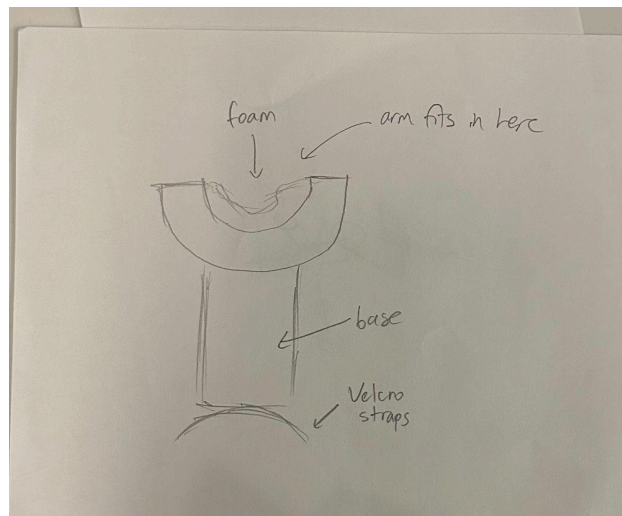


Figure 27: C-Shaped Support

Collar Support

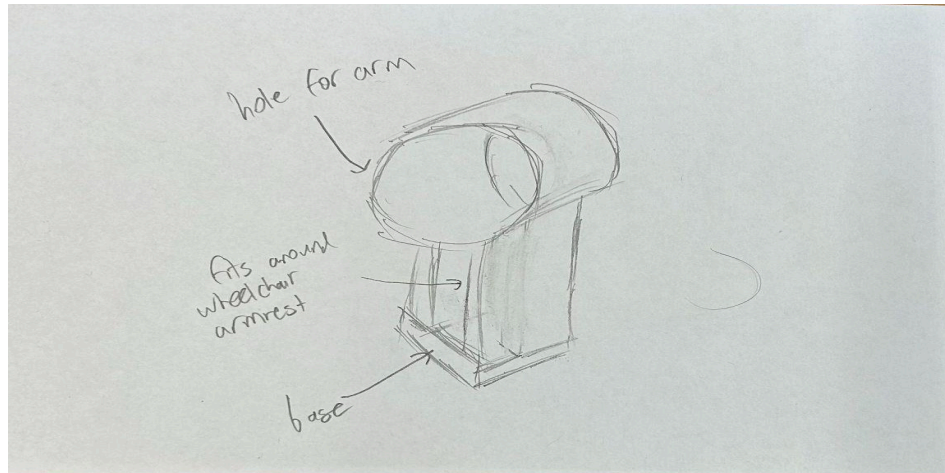
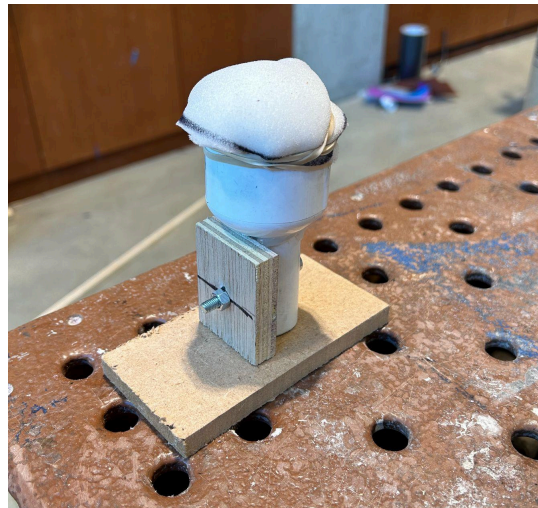


Figure 28: Collar Support

Cup Support



Figures 29-31: Cup Support

The 3 mockup ideas displayed above (c-shaped, collar, and cup supports) were only presented to Dane and Rachel in their sketched form since no physical mockups had been fabricated at the time. Given the similar theme of arm support across these mockups, similar questions to those asked about the Stabilizer were asked for each of these mockups. Additionally, Dane and Rachel's thoughts on the shapes and functions of the sketched designs were recorded.

Joystick Resistance

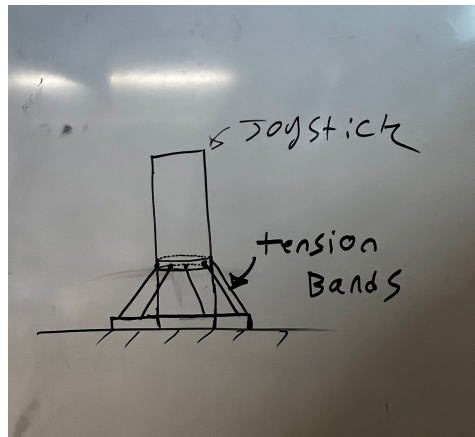


Figure 32: Joystick Resistance

This mockup idea was created in the interest of addressing the navigation issue from another point of view - the need for increased control for Dane and Rachel of their joysticks. Again, there were no physical mockups available for testing at the time, but inquiries were made about Dane and Rachel's comfortability with their current joysticks and their thoughts on attachments for the joystick in general as well as the specific mockup idea.

Results

Initial feedback from Rachel on the physical Attachable Arm Stabilizer mockup was positive. The taller version (red) was slightly too tall for comfortable use, but the 2 in. elevation mockup (blue) fit comfortably for Rachel. She was able to drive smoothly and in a controlled manner while using the blue Stabilizer and was even able to reverse her wheelchair. Rachel did say that she would prefer a more comfortable material and a squishier foam for the top of the Stabilizer. She also stated that a better-sculpted Stabilizer design for the Stabilizer would be appreciated. When attempting to support Dane's arm with the Stabilizers, they were uncomfortable for him. This is because there is much less of a gap between his elbow and natural armrest than there is for Rachel.

Both rejected the idea of the C-shaped support and showed mild interest in the collar support. As for the cup support design, Rachel displayed extreme interest in this idea even more so than the Attachable Arm Stabilizer design which she also liked. She liked both the shape and functionality principles of the cup support mockup and reiterated her past statement that some form of arm support would be of interest to her. Although Dane did not respond positively to these mockups, he did venture to mention that a device that would support his arm in the extended position needed to operate his joystick would be of interest to him. The fact that physical mockups were not tested with Dane is not ideal at this point, however, Dane's feedback was very informative towards the next steps in the design process.

The final mockup idea (joystick resistance) was not accepted positively. Both Dane and Rachel reiterated the statements they had made last visit which was that they are entirely comfortable with their joysticks and do not want any additional attachments for them to hold. Although the joystick resistance is not something that is held, which was communicated to Dane and Rachel, they firmly stated that they did not want attachments for their joysticks, and Dane has explicitly said that he will not try the joystick resistance.

Discussion

With the information learned from these 2 visits as well as communications with other teams, the idea has been solidified that the arm support avenue is the best course of action at this time. Dane and Rachel have both displayed a great interest in the idea of support for their arms, although in different ways and have provided lots of feedback concerning the current and future mockup designs. Rachel was comfortable with the first Stabilizer design (only the blue size) and mentioned that she would like a more form-fitting design with softer cushioning. Testing revealed that Dane would like support for when his arm is extended, due to the setup of his wheelchair, rather than elevation support. The tests have made it very clear that joystick attachments are not something that Dane and Rachel would use due to both inconvenience and personal preference. Given Rachel's interest in cup-like support, mockups for cup support will be tested during the next visit to the NSSRA. From Dane's feedback, the Stabilizer design will be altered to support his arm from behind when he is operating his wheelchair. The design should only be in the support position when Dane needs it to be there. Overall, the main avenue for improving Dane and Rachel's navigational abilities has been identified, primary designs have been created and tested based on the feedback received from Dane and Rachel, and materials to update the project definition to be more specific to the final prototype have been gathered.

Appendix E: User Observation Summary

On Monday, January 22nd, 2024, Kiran and Tooni traveled to the NSSRA facility in Highland Park, IL to meet Dane, Rachel, and Mr. Joe Hart and make observations of their situations. Although Dane was absent due to an illness, Kiran and Tooni spoke with Rachel and Mr. Hart, and obtained measurements of the elevator and wheelchair. Rachel's navigation of the NSSRA's obstacle course was also observed, as well as making turns.

Methodology

The observations occurred in the Great Room of the NSSRA facility, where NSSRA participants socialize and engage in recreational activities. An interview with Rachel was conducted and videos were taken of her steering the wheelchair. Dimensions of the wheelchair were measured with a tape measure. Lastly, Rachel was observed boarding the bus, as well as how the staff operated the technology used to enter the bus. Mr. Hart also showed locations where wheelchair users had crashed into the wall and elaborated on the differences between Dane and Rachel's personalities and navigation difficulties.

User Information

Dane and Rachel have cerebral palsy and use motorized wheelchairs. Dane enjoys watching superhero movies and video games. Rachel values her independence and is a fan of Chicago sports. Both have a vibrant sense of humor, such as laughing when crashing the wheelchair. They have difficulty navigating the wheelchair, particularly making sharp turns. This often causes crashes with the walls. Due to this, Dane and Rachel frequently require staff assistance.

Wheelchair Information

Both Dane and Rachel use a Permobil 2019 F5 Corpus power wheelchair. In the past, Dane used a wheelchair which allowed him to climb stairs. However, within the last year, Dane switched to his current wheelchair. Rachel's wheelchair was observed to have the following dimensions and features:

- Length: 45 in
- Width: 25.5 in
- Minimum turning radius: 30 in
- Joystick on the left side of the wheelchair
 - Covered in decorative tape to make it larger and easier to control

- Tape was added by Rachel's father
- Two dials in front of joystick, one of which controls speed
- Watch attached to joystick panel

Challenges

Rachel shared that turning corners was one of the most difficult tasks since there was limited visibility. Mr. Hart showed the team members the damage caused to the wall, which consisted of dents and scratches on the wall. Furthermore, boarding elevators is a difficult task for Rachel, since the elevator doors often close on the wheelchair. Because of this, staff assistance is usually required to keep the elevator doors open. The team members recorded the following observations about the elevator:

- Length of elevator doors: 42 in
- Length of interior: 62 in
- Width of Interior: 80 in
- Doors close after 15 s

Existing Obstacle Course

The current obstacle course consists of half cones arranged in a path, with two lines of cones on either side. When observed by the team members, the path began wider and then narrowed. Towards the end, the obstacle course led into a hallway, with walls on either side in addition to the cones. Rachel was observed completing the obstacle course. When she reached the end of the hallway, she turned the wheelchair around and exited the obstacle course in the same way that she entered. As she was driving through the wide section of the course, Rachel drove over one cone. Rachel stated that the obstacle course was not entertaining.

Pros to Existing Solution

- Inexpensive and affordable
- Can be adapted to different rooms/environments
- Easy to set up and take down

Cons to Existing Solution

- Lacks a structure or organization
- Only consists of cones

- Not entertaining or useful for users

Boarding the Bus

Rachel was observed boarding the bus to go to Target. The bus featured a device that elevated Rachel into the vehicle. A caretaker on the outside helped Rachel board the ramp by making movements with the joystick. Once Rachel was on the ramp, the caretaker strapped her in. The machine then raised Rachel to the level of the bus. After this, another staff member on the inside of the bus unstrapped Rachel and helped her move into the interior of the bus.

Appendix F: Instructions for Construction

The following materials are necessary for the construction of both Attachable Arm Stabilizers:

Table 3: Necessary Materials (Complete itemized list of materials can be found in Appendix E)

Material	Specifications	Quantity
Plywood	4" x 13" softwood panel	1
Nylon Velcro straps	1" x 68", black	1
Metal buckles	1" x .5" rectangles	4
Staples	½" industrial staples	17
Wood screws	¾", black	8
Hot glue	.44" diameter	4 sticks
Polyurethane foam	1" x 12" x 24" sheet	1 sheet
Broadcloth fabric	303 in ² green, 378 in ² blue	1, 1

The following tools/resources necessary for construction are listed below:

- Band saw
- Hot glue gun
- Industrial stapler
- Scissors
- Drill (with drill and phillips head bits)

Step 1: Prepare Velcro Straps

1. Cut the Velcro straps into four 17" strips using scissors
2. Slide one buckle over each strap and fold 2" of strap over it to hold it in place (see Figure 33)

Step 2: Construct Stabilizer Body

1. Cut one 3.50" x 9.00" rectangle and one 3.50" x 5.00" rectangle out of the 23/32" plywood using bandsaw
2. Stack foam for Dane's Stabilizer

- a. Cut three 3.50" x 5.00" rectangles out of polyurethane foam (bottom left corner proceeding rightward in Figure 34)
 - b. Stack the three rectangles on top of each other, making sure corners are aligned
 - c. Use hot glue as appropriate to fasten the layers of stack to each other (it is recommended to draw an "X" from each corner of each rectangle to its opposite)
3. Stack foam for Rachel's Stabilizer
 - a. Cut two 3.50" x 9.00" rectangles out of polyurethane foam (large rectangles in bottom right corner in Figure 34)
 - b. Stack the three rectangles on top of each other, making sure corners are aligned
 - c. Use hot glue as appropriate to fasten the layers of stack to each other (it is recommended to draw an "X" from each corner of each rectangle to its opposite) (see Figure 35)
 - d. Cut four 3.50" x 4.25" rectangles out of polyurethane foam (middle left, top right corner of Figure 34)
 - e. For each *pair* of these rectangles, repeat steps 2.3b-c
 - f. Complete steps 2.5a-b, then hot glue bases of triangular prisms to the wood + foam block created in steps 2.3a-d such that their slopes descend towards each other
 - g. Proceed to step 3
4. Shape Dane's Stabilizer
 - a. Trace a line similar to the dashed arc depicted in Figure 36 onto the 3.00" x 5.00" side of the block created in step 2.2c
 - b. Cut along line using bandsaw
5. Shape Rachel's Stabilizer
 - a. On each of the two smaller blocks created in step 2.3e, trace a line similar to the dashed arc depicted in Figure 37
 - b. Cut along line using bandsaw; return to step 2.3f

Step 3: Encase in Fabric Cover

1. Cut a 12" x 22" rectangle of green fabric and a 14.5" x 21.75" rectangle of blue fabric
2. Holding its wooden side up, pull green fabric tightly around Dane's Stabilizer, focusing on fastening the longer sides of the Stabilizer first
3. Use 2 staples on each side to fasten fabric to base
4. Proceed to front and back, neatly folding the fabric into itself such that the outside of the Stabilizer is smooth, using 2 staples to fasten the front fabric and 2 to fasten the back
5. Cut off excess fabric on bottom of Stabilizer
6. Repeat steps 2-5 for Rachel's Stabilizer

- a. NOTE: for Rachel's Stabilizer, to avoid uncomfortable slack fabric on the top of the Stabilizer, you may find it useful to pull the center of the fabric, where the bottom of the slopes lie, taught first and fasten, then proceed as usual
7. Cut a 6.525" x 5.875" rectangle of green fabric and a 5.525" x 11.125" rectangle of blue fabric
8. Fold the sides in to create a 3.5" x 5" rectangle of green fabric with no frayed edges; use hot glue to secure the fabric to itself after folding
9. Repeat a similar process to create a 3.5" x 9" rectangle of blue fabric
10. Use hot glue to fasten each rectangle to the *bottom* of its corresponding Stabilizer (this is meant to cover up the staples and uneven edges of the stapled fabric); make sure corners are carefully aligned before gluing

Step 4: Assemble/Attach to Wheelchair

1. Line up the buckled end of the velcro strap from step 1 such that the buckle lies about an inch and a half out from the edge of the block, soft side up, and about 1.5" in from the front or back of the Stabilizer
2. Line up the other three straps, using same criteria from step 4.1
3. Fasten each strap to its corresponding block using 2 wood screws per strap, as shown in Figure 38
4. The Stabilizers are now ready for mounting: see Appendix G for use

Figures

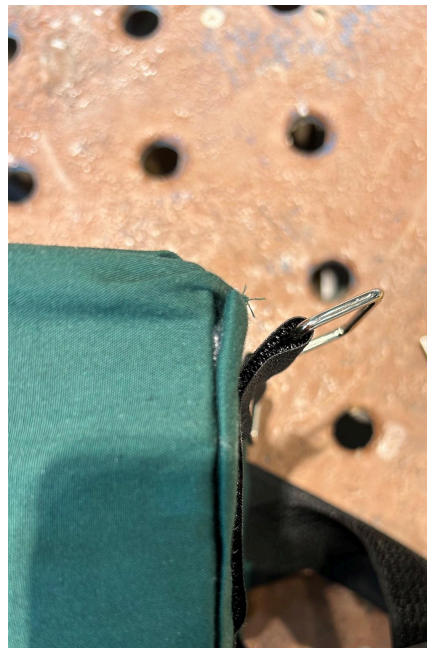


Figure 33: Folded Velcro Strap

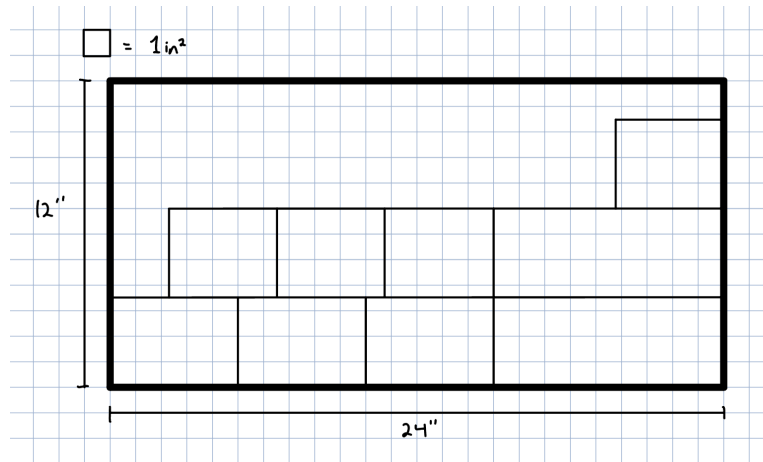


Figure 34: Foam Cutting Map

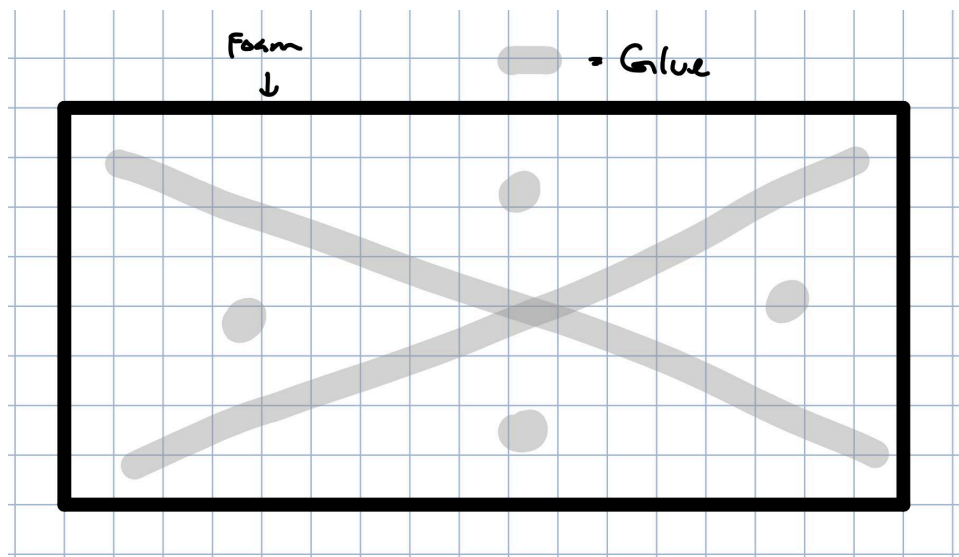


Figure 35: Glue Placement

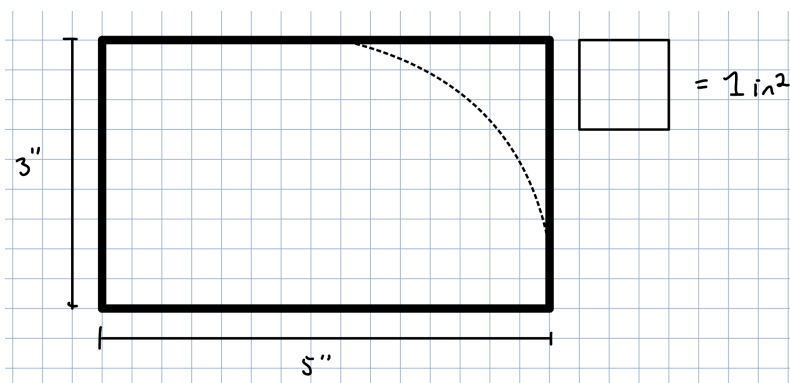


Figure 36: Dane's Stabilizer Slope Shape

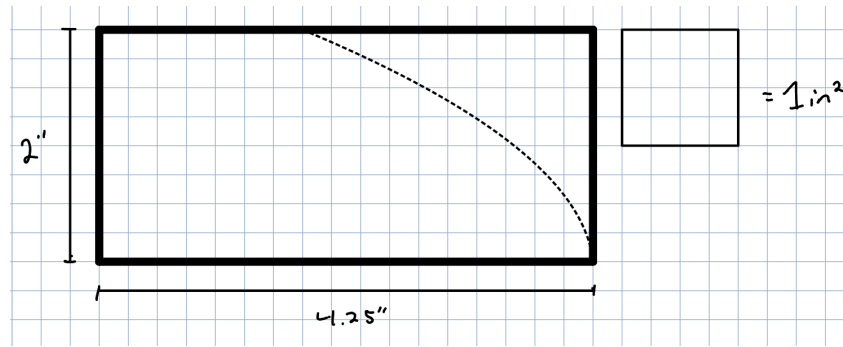


Figure 37: Rachel's Stabilizer Slope Shape



Figure 38: Wood Screw Placement

Appendix G: Instructions for Use

The following outlines the instructions for using the Attachable Arm Stabilizer

Initial Set Up - Attaching to Wheelchair (For NSSRA Staff or other Caregiver)

1. Ensure that the user's arm is away from the top of the natural armrest so that there is enough space for the Stabilizer to attach onto.
2. Loosen Velcro strap on the bottom of the Stabilizer.
3. With the bottom base above the top of the natural armrest, slide the Stabilizer over the wheelchair armrest so that the strap surrounds the armrest.
4. Tighten the Velcro through the loop so that the Stabilizer is held tight in place on top of the natural armrest.



Figure 39: Attachable Arm Stabilizer Fastened to Natural Armrest



Figures 40-41: Stabilizers Strapped to Mock Natural Armrests

Detaching

1. Move the user's arm off of the cushion.
2. Unstrap the Velcro from the bottom of the natural armrest.

3. Pull the Velcro out of the loop to loosen the Stabilizer.
4. Slide the Stabilizer off of the wheelchair arm and stow it away somewhere safe.

Cleaning

1. Detach the Stabilizer from the wheelchair according to the steps in the previous section.
2. Wash the outside cloth using any fabric-related soap.
3. Leave cloth to fully dry out before using the Stabilizer again

Appendix H: Bill of Materials

Table 4: Bill of Materials

Item	Description	Quantity	Vendor	Part Number	Unit Cost	Total Cost
Broadcloth Fabric (1)	Blue color	378 in ²	Vogue Fabrics	201226	\$3.65	\$16.27
Broadcloth Fabric (2)	Green color	303 in ²	Vogue Fabrics	201226	\$3.65	
Polyurethane Foam Sheet	24" x 24" 1" thick Gray color	175 in ³	McMaster-Carr	8643K552	\$50.01	\$68.56
Nylon Velcro Straps (+ Buckles)	1" x 16' hook and loop straps	1 roll, 25 buckles	Amazon (YMCRLUX)	V0525	\$9.99	\$9.99
Hot Glue	.44" diameter hot glue sticks	4 sticks	Amazon (AdTech)	W220-14ZI P50	\$6.28	\$6.28
Staples	½" construction staples	17	Home Depot	202061313	\$12.98	\$12.98
Wood	23/32" soft plywood	3.5" x 14"	Home Depot	100061386	\$45.00	\$45.00
Wood Screws	¾" black wood screws	8	Amazon (TPOHH)	KA4SS18-8	\$7.49	\$7.49