Forearm Activated Bike Shifter and Braking Mechanism for Safer Hand-Cycling

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Augmenting Human Dexterity – Spring 2023
Term Project: Report and Research Proposal

Abstract

This project aims to address the challenges faced by handcyclists with hand-affecting conditions, specifically those with incomplete quadriplegia. Handcycling requires upper body strength to power the cycle and wrist strength in order to shift and brake. However, individuals with incomplete quadriplegia often have limited wrist strength. This can hinder their ability to safely activate the brakes or shift on their handcycle. To address this issue, we propose a modification to the traditional sit-down road bicycle that replaces the need for wrist movement in shifting and braking with shoulder movement. Our modification is an attached device that moves the activator peg from the wrist to the user's forearm, allowing for braking or shifting by lifting the arms away and pushing the peg outwards by utilizing shoulder movement. Many with incomplete quadriplegia use a wheelchair so the shoulder muscle group is frequently utilized and well formed, meaning the outwards arm movement required for brake and shifting activation is an intuitive one. This affordable and easy-to-use modification has the potential to make handcycling safer and more accessible for individuals with limited wrist mobility and strength. No prior studies have focused on using shoulder movement to activate braking or shifting mechanisms for this population. Our research seeks to fill this gap and evaluate the feasibility and effectiveness of this modified design.

I. Introduction

This project targets handcyclists with hand-affecting conditions and is specifically targeted at those with incomplete quadriplegia. Handcycles demand upper body strength in order to power the bike, while requiring wrist strength to shift and brake. A common problem in those with incomplete quadriplegia is the lack of strength in the wrist flexion movement. Depending on the design of the handcycle, this either limits or completely prevents a user from being able to safely activate the brakes on their bike. There is a need for a device that allows this population of individuals to safely break their bike.

A. Background

Incomplete quadriplegia is a condition where there is partial paralysis of all four limbs, usually caused by damage to the cervical spinal cord [1]. Incomplete quadriplegia can result in limited function of the hands and wrists. For individuals living with this condition, completing everyday tasks can be a challenge. While there are various assistive devices available to help with daily activities, there are still many areas where these individuals face difficulty [2].

One particular challenge for people with incomplete quadriplegia is biking, especially with traditional handcycle braking systems. There is an existing attachment for paraplegic and incomplete quadriplegic individuals called QuadGrips (Figure 8). These grips are easily interchangeable between handcycles and are adaptive to most riders with disabilities affecting the hands. The outer pin of the device is accessible with outward flexion of the wrist, hitting it with the back of the hand. The right hand shifts the bike while the same movement on the left hand activates the brake. The rider's hands are strapped to the hand crank with a hand-grip assistive device that enables the rider to generate power on the bike. However, the attachment requires wrist flexion in order to brake and shift gears. It is common for incomplete quadriplegia to result in low wrist strength making this system of braking and shifting unsafe or impossible to use. This was a challenge that our team sought to address with our modified handcycle design.

We hypothesize that modifying the traditional handcycle to eliminate the need for wrist movement in shifting and braking by replacing it with shoulder movement will enable easier and safer biking for individuals with limited wrist mobility and strength. This modification involves attaching a piece to the bike that moves the peg a user would normally hit with their wrist back so it is on the users forearm. Now, to brake or shift, one lifts their arms away from them, pushing the peg and new arm outwards, activating the brakes or shifting gears. Our modification is affordable and easy to use, making it accessible to a wide range of users.

To our knowledge, there have been no studies focusing on the use of shoulder movement to activate the brake or shifting mechanism on handcycles for individuals with incomplete quadriplegia. This study aims to fill that gap and provide insights into the feasibility and effectiveness of this modified design.

B. Overview

In Section II, we incorporate insights from an interview with an athlete to understand his needs and experiences. In Section III, we suggest a device to improve the wrist mobility needs of the athlete to increase safety while biking through shifting and braking mechanisms. We also describe a protocol to test the usability and functionality of our new bike mechanics. We hypothesize that by lengthening the point of contact the rider has with the handlebars will enable more power from the forearm when extending the wrists to shift and brake on the racing bike.

II. Interview case study

We reached out to a connection from the Challenged Athletes Foundation who then further put us in touch with a young-man with incomplete quadriplegia. We conducted a 90 minute interview to determine his needs. The interview was conducted in person with audio recording over Zoom. Our team of three interviewers consisted of one note taker and two main interviewers that handled the questions.

The need-knower had a large athletic background and provided information on how he adapted to new sports and activities after his injury and what types of assistance and adaptive devices exist for individuals like himself. The need-knower opened up room for many questions, and we identified challenges that could be explored more through our project as seen in Table I. One major takeaway from the interview was that the need-knower has the greatest wrist strength with extension rather than flexion. The need-knower identified how his racing bike utilizes flexion to shift and brake which causes some danger to his riding since he can't provide enough strength to activate the mechanisms. He noted that he straps his wrists onto the handles to gain enough power over the crank but in doing so he cannot rotate his wrists with enough force to shift or brake. Additionally, this inability to shift or brake can cause further harm to the need-knower in situations where there may be traffic or large hills.

Throughout our interview, the need-knower placed a large emphasis on his independence. He uses as minimal assistive devices as possible and values the strength he still has in his body. This challenged us to think creatively and opened opportunities for us to expand our brainstorming beyond the obvious solutions. Our need-knower led us to our ultimate decision in our project topic as he wants to complete his first triathlon and could use a new bike mechanic system in order to do so.

Prompt/Theme	**Interview statement**	**Interpreted need**
Goals	"I want to do a triathlon"	He's active and wants to try out a new sport
Typical Uses	"I like mountain biking but I don't ride my road bike as much because it's hard to shift"	His road bike needs to shift the way his mountain bike does
Likes- Current System	"I like being able to strap my hands in tight. It gives me a lot more power to go faster"	He wants to have more control over his bike at high speeds
Dislikes- Current System	I can't move my hands outward to shift the gears	The gears need to be adjusted to shift in a way that works for his hand strength

TABLE I: Condensed User-Needs Chart from Primary Interview.

III. Proposed Device & Test Methods

A. Proposed Device

Our proposed device, the Handcycle Adaptive Braking and Shifting System (HABSS), is shown in Figure 1. The HABSS is a simple mechanism designed to allow the braking and shifting capabilities of handcycles to be used by individuals with limited wrist strength. It provides a comfortable and adjustable solution to shift and brake handcycles for those with incomplete quadriplegia by utilizing shoulder motion to activate the braking and shifting systems. The HABSS integrates into the existing handcycle technology seen in Figure 8, utilizing the same action peg from the system. Appendix A contains detailed design files for replicating the HABSS.

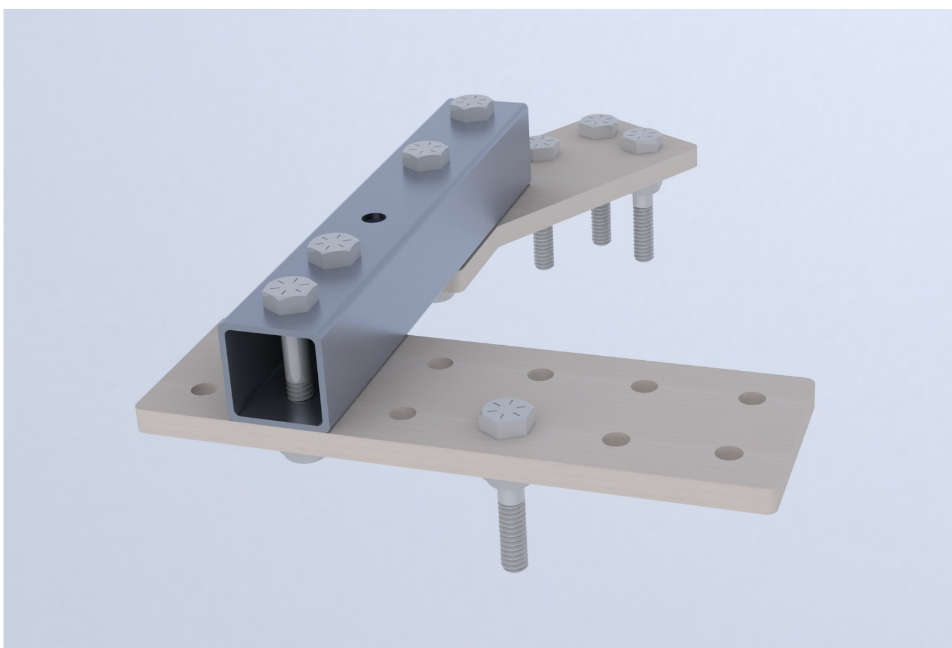

Fig. 1: Final Design

1. **Device Components:** The HABSS consists of the following main components:
   a. Connector Plate: Attaches the device to the existing handcycle, providing a stable and secure connection.
   b. Adjustable Arm: Running along the length of the user's arm, it allows for a customizable fit that accommodates different arm lengths and seat positions through multiple mounting points on the arm.
   c. Offset Plate: Peg mounting plate with multiple options for placement.

2. **Device Operation:** The HABSS operates by transferring activation of the handcycle's brake and shifting mechanisms from a flexion-based wrist motion to a shoulder-based motion. This modification enables a user to engage the brakes and shifter using the same muscles employed from pushing a wheelchair, providing an intuitive and accessible control method. To shift up, the user moves the right peg out a small distance. To shift down, the user moves the right peg out a farther distance. To brake, the user moves the left peg out a distance relative to the braking force they desire.

3. **Device Adjustability:** The HABSS was designed with adjustability in mind to accommodate a wide variety of users and seating positions. The offset plate features multiple holes for adjusting the peg's position, while the adjustable arm allows for fine-tuning of the offset plate's position ensuring optimal comfort and functionality.

4. **Device Manufacturing:** The initial prototypes of the HABSS were made using laser-cut plywood for the connector and offset plates and one-inch square aluminum tubing for the adjustable arm. Future iterations of the device could utilize more durable materials such as carbon fiber or aluminum to enhance their longevity and safety. Chamfering of edges and wrapping hard parts in soft handlebar tape make sure the device is easy to hold when adjusting and comfortable to use.

B. Test Methods

To evaluate the effectiveness and usability of the HABSS, we suggest four phases of testing. We completed the first stage while testing our prototypes. The testing will assess the system's function and its ability to improve the cycling experience for individuals with limited wrist strength utilizing handcycles. We plan to submit a protocol for review through the Internal Review Board for the Protection of Human Subjects. We also completed the CITI training Group 1: Biomedical Research Investigators as of April 2023.

1. **Device Integration:** The HABSS is the product of multiple prototypes and tests. These prototypes and tests are described in detail in Appendix B. Throughout our tests, we discovered and addressed multiple issues. We shortened the adjustable arm length by three inches to address the issue of the arm being too long. We also updated the connection plate to hold a screw that connects to the brake cable mechanism, achieving the same result as our jury-rigged solution shown in Figure 5. The result is the system shown in Figure 1 which integrates into our need-knower's handcycle and does not inhibit normal cycling behavior.

2. **User Integration:** The HABSS must be comfortable and easy to use for all users. To ensure this, we propose testing the HABSS with multiple subjects on their personal handcycles. We would adjust the HABSS to them and receive feedback on its fit and usability. This stage may involve multiple prototype iterations to create a broadly applicable design.

3. **Load:** We propose testing the required forces for nominal use of the HABSS. This can be done by measuring the forces users exert on the device while using it. Then, calculations or simulations can be completed to determine the type and thickness of material required to withstand the nominal forces with a desired factor of safety.

4. **Safety:** The HABSS must be safe to operate, including in the event of a crash. To ensure this, we propose completing a Failure Mode and Effects Analysis (FMEA) on the HABSS. This analysis should take both normal use and extreme situations into account. The device must also pass all applicable safety standards and regulations.

C. Expected Outcomes

After demonstrating the functionality of our re-designed shift and braking mechanisms, our need-knower would be able to use our device to shift and brake on his bike in a safer and easier way, enabling him to go on longer rides and pursue his cycling dreams.

IV. Intellectual Merit

Our study can be generalized to address the issue people with limited dexterous manipulation ability face when articulating conventional brake and shifting levers on bikes. Conventional brake and shifting levers are not designed with limited dexterous manipulation in mind, and they generally require a strong grip strength to activate. This leaves limited options to people without full dexterity such as those experiencing incomplete quadriplegia.

Our study addresses this issue by shifting the actuary location up the arm, moving it from the fingers and hand up to the forearm. This increases accessibility by requiring less dexterity to manipulate the brake and shifting levers.

For future work, we propose a redesign of our device for production. One example of this is shown in Figure 2. This redesign consists of only one part. It can be easily manufactured from an aluminum plate using a waterjet cutter. Further testing should be done to determine the expecting loads the device will experience and calculate the necessary thickness of the material to withstand these loads with the desired factor of safety. The design has a half-inch fillet on all corners for safety. We also propose completing an FMEA test on the design to ensure its safety.

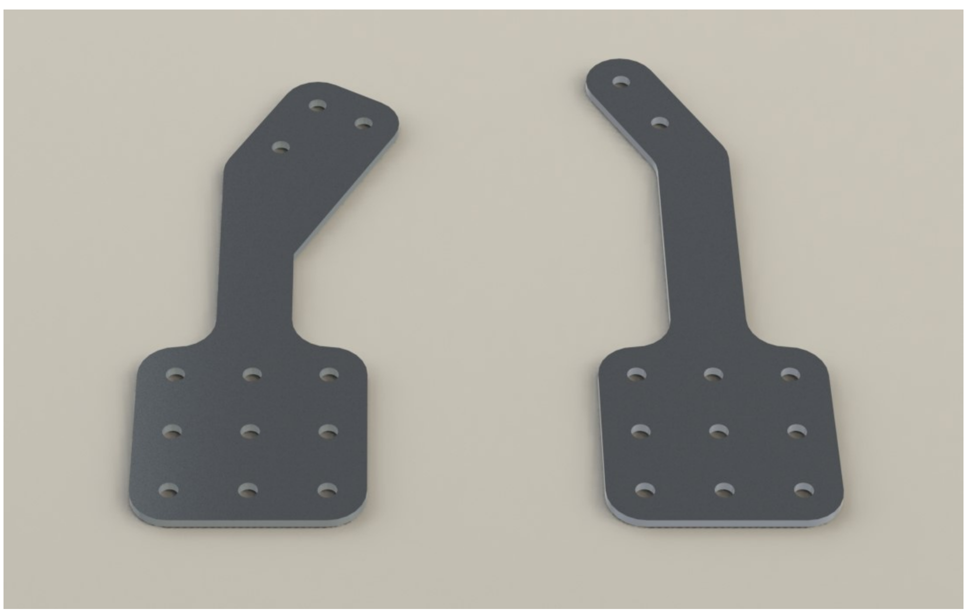

Fig. 2: Proposed Design

V. Broader Impact

Our device is designed specifically for our need-knower; however, given the simple extension of the arm of the shifters, the device can easily be adapted to other individuals with similar disabilities. This demonstrates the potential of being beneficial to a multitude of cyclists. We propose an updated design consisting of a single piece of aluminum (see Figure 2) which can attach to the existing Quadgrip system and be adjusted for a range of potential users. Recreational and professional cyclists, whether with or without disabilities affecting the wrists and hands, can use the product. While this product is intended to be used by our need-knower, it opens up the opportunity for other para-cyclists who may face similar issues to find safety and ease with our product.

REFERENCES

[1] N. V. Bosch A, Stauffer ES, "Incomplete traumatic quadriplegia: A ten year review," vol. 216, no. 3. JAMA, 1971, pp. 473–478.

[2] A. Prochazka, M. Gauthier, M. Wieler, and Z. Kenwell, "The bionic glove: an electrical stimulator garment that provides controlled grasp and hand opening in quadriplegia," *Archives of physical medicine and rehabilitation*, vol. 78, no. 6, pp. 608–614, 1997.

Appendix A
Design Files for the HABSS

For more information on the design files and copies of the SOLIDWORKS models, contact Todd Russell at russellt@berkeley.edu.

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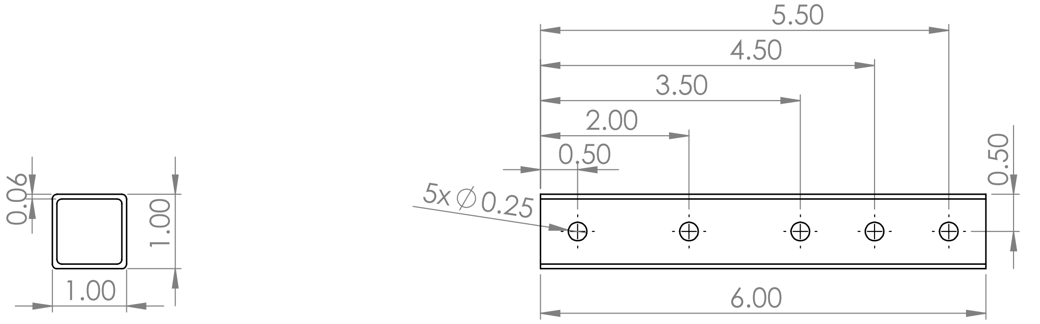

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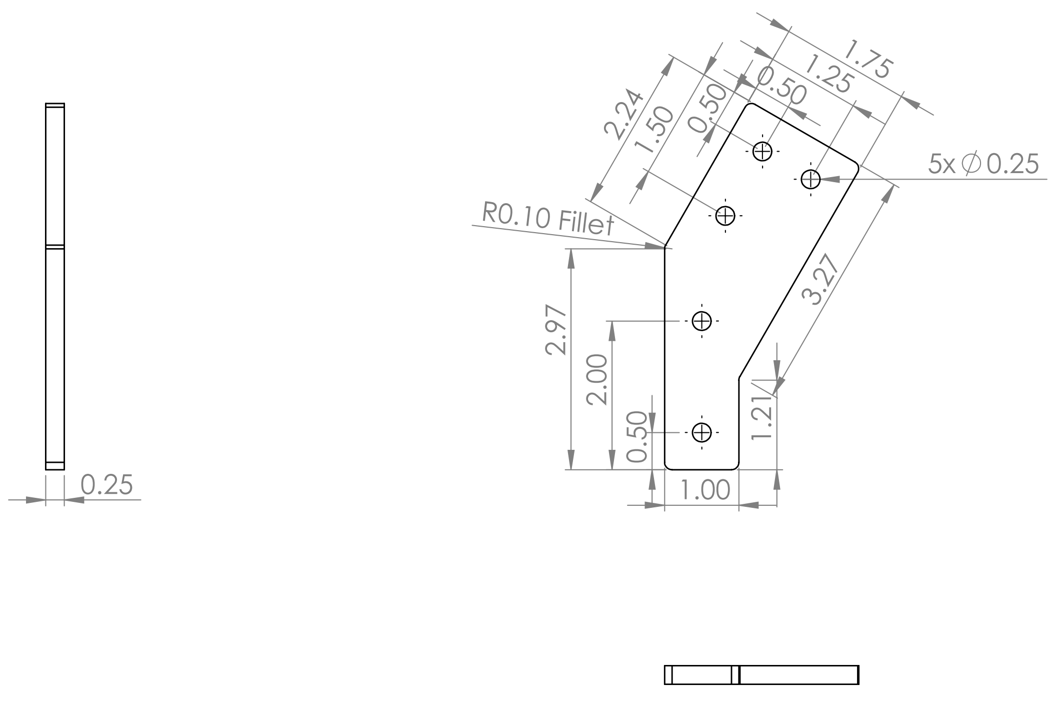

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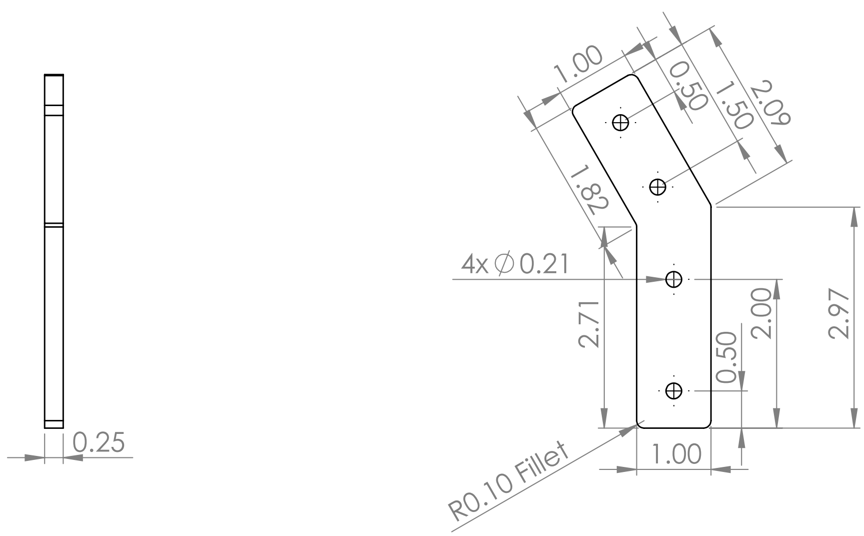

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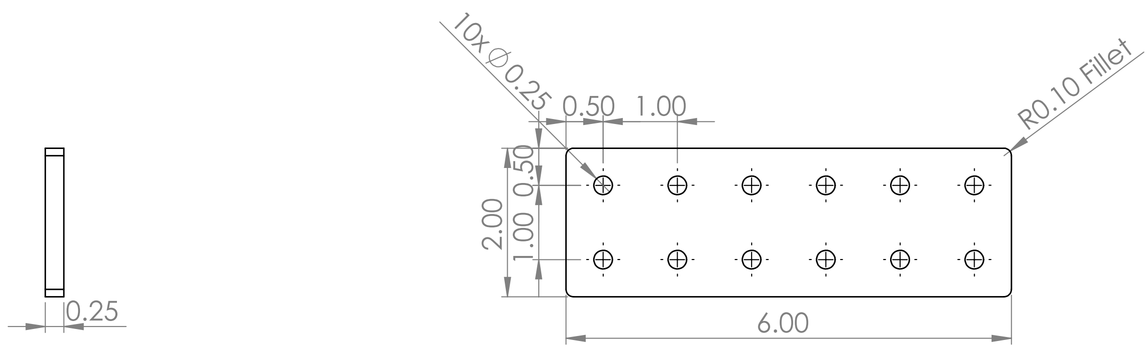

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APPENDIX B
PROTOTYPES AND TESTING

We initially planned on using a pulley system attached to the rider's elbow to reroute the need knower's current brake and shifting system. However, we decided to extend the current device in order to make our product more adaptable and quicker to activate in the event of a situation that requires fast reaction times.

A. Prototype 1

Our initial concept, Prototype 1, is displayed in Figure 3. Prototype 1 consists of three main components: a connector plate which connects the device to the existing technology, an arm which runs along the length of the user's arm, and an offset plate which holds the activation pin. This concept shifts the action pin from a flexion-activated location to along the forearm. By shifting the pin location, we changed the muscles necessary to activate the brakes and shifter. Prototype 1 utilizes a shoulder motion. This relies on muscles our need-knower uses in everyday life through pushing his wheelchair, meaning our device is activated through a motion our need-knower is comfortable completing. Our design was inspired by a forearm-actuated pin on an electric wheelchair.

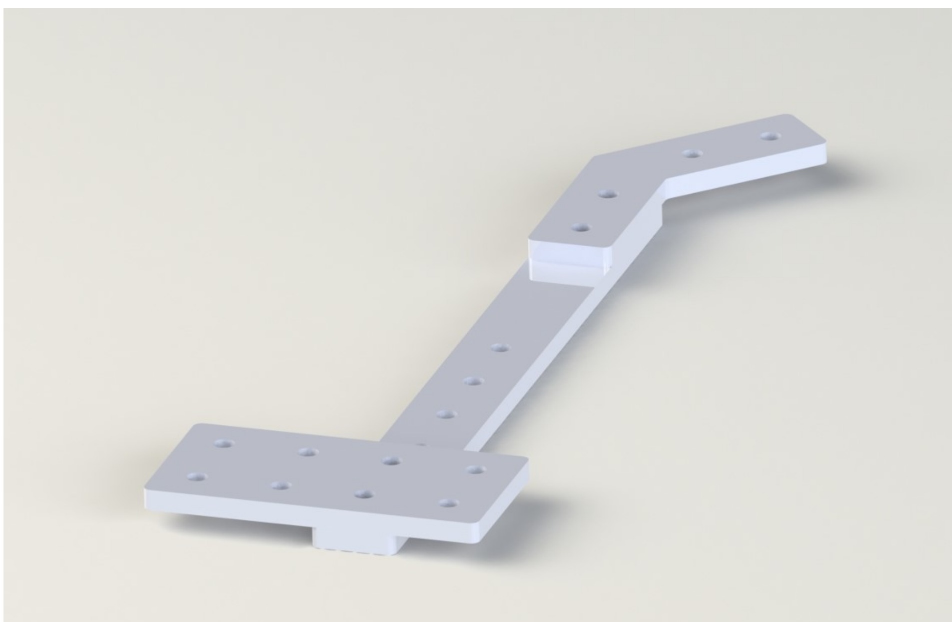

Fig. 3: Prototype 1

One of our prime design criteria was adjustability. We wanted our device to be able to fit a range of riding positions and riders. To complete this goal, we designed an offset plate which the pin attaches to. This plate has multiple holes on it to enable the user to adjust the position of the pin in both the direction along the arm and the direction perpendicular to the arm. In order to keep the offset plate small, we made the connection point between the plate and arm adjustable rather than creating a larger but permanently placed plate.

B. Prototype 2

We updated Prototype 1 to a new design, Prototype 2, shown in Figure 4. The main motivation for our changes was manufacturability. Prototype 2 can be manufactured from one-inch square aluminum tubing and laser cut plywood.

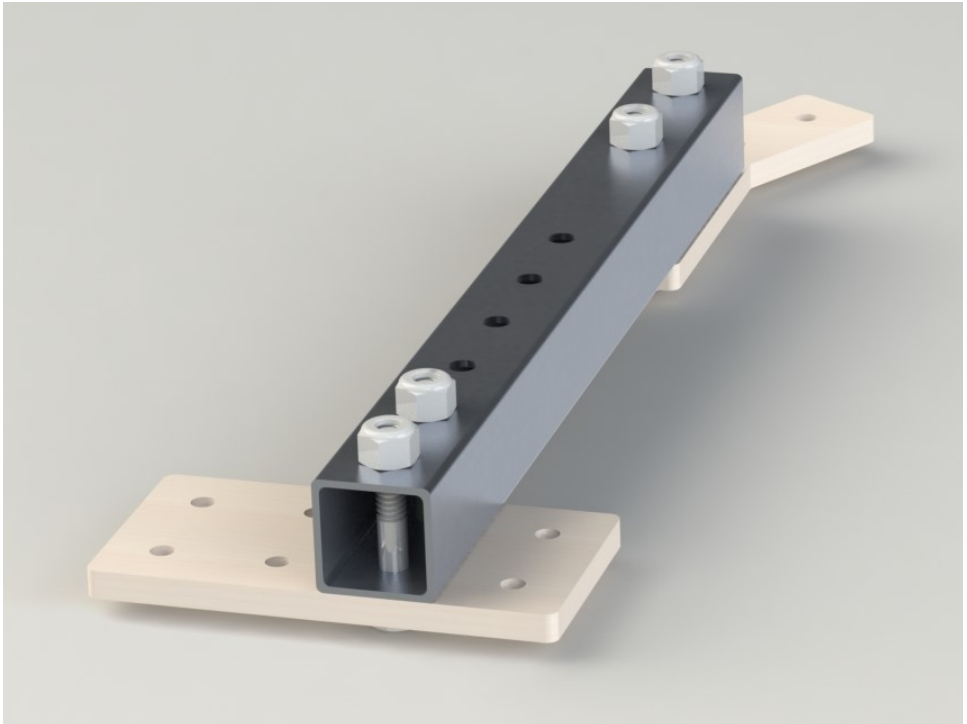

Fig. 4: Prototype 2. Updated for Manufacturability

After manufacturing Prototype 2, we tested the brake assembly on our need-knower's handcycle. Our testing was a major success. We were able to brake effectively while pedaling. However, through our testing we discovered two main issues to fix.

First, the arm was too long. This caused it to restrict the pedaling motion as the arm would catch on the user's chest when attempting to complete a full rotation. To get around this issue during testing, we moved the connection plate to lower down on the arm, shortening the effective arm length.

Our second issue was the arm was able to continue moving after the brake was fully engaged. This means the device would not return to its neutral state when released; rather, it would only move back partway until the brake was disengaged. This meant when the user went to active the brake again, they would not be able to reach the activation pin. Initially, we addressed this issue by adding another pin on the inside of the user's arm. However, his caused discomfort while riding. The next solution we implanted was directly connecting the connection plate to the brake cable mechanism. This constrained the device from overextending and offsetting its position. In Prototype 2, we achieved this with tools at hand as seen in Figure 5.

Our testing enabled us to produce our final design in Section III. We learned from issues which arose during testing, culminating in a final product which seamlessly integrates into our need-knower's handcycle.

APPENDIX C
INVESTIGATIONAL DEVICE DETAILS

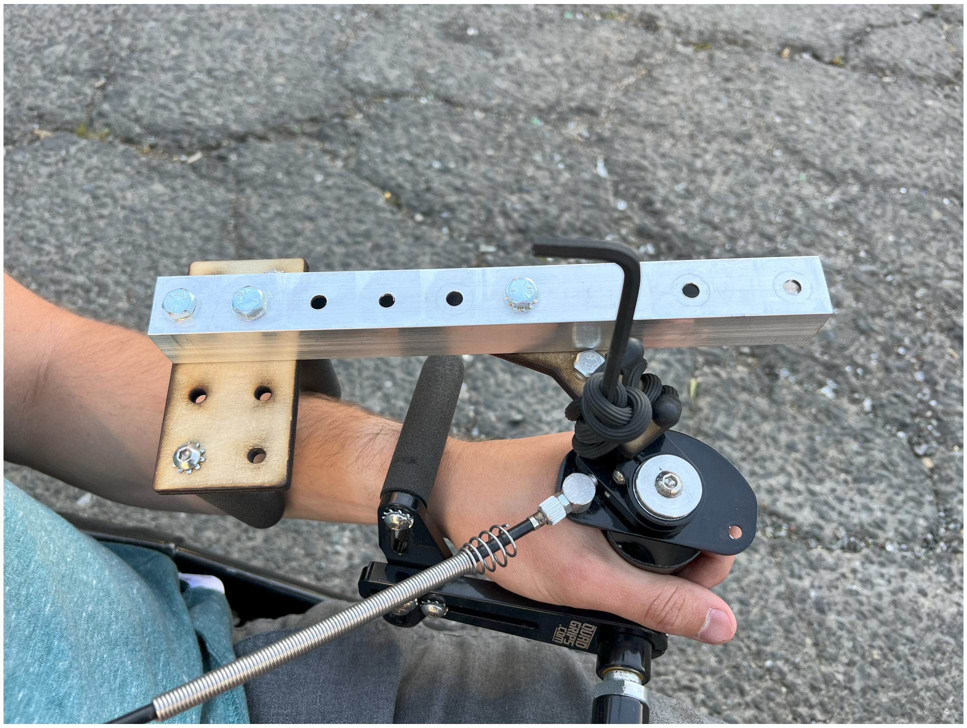

Fig. 5: Jury-Rigged Fix

	Weight	Computer Mount	Road Bike Shifters	Collapsible Bag
Cost	2	2	-1	1
Safety	5	2	2	1
Feasibility of Creation	4	2	0	0
Impact on life	5	-2	2	1
Ease of use	3	1	2	-1
Appearance	1	0	1	-1
Total	-	15	25	8

Fig. 6: Decision Matrix Used for Design Selection

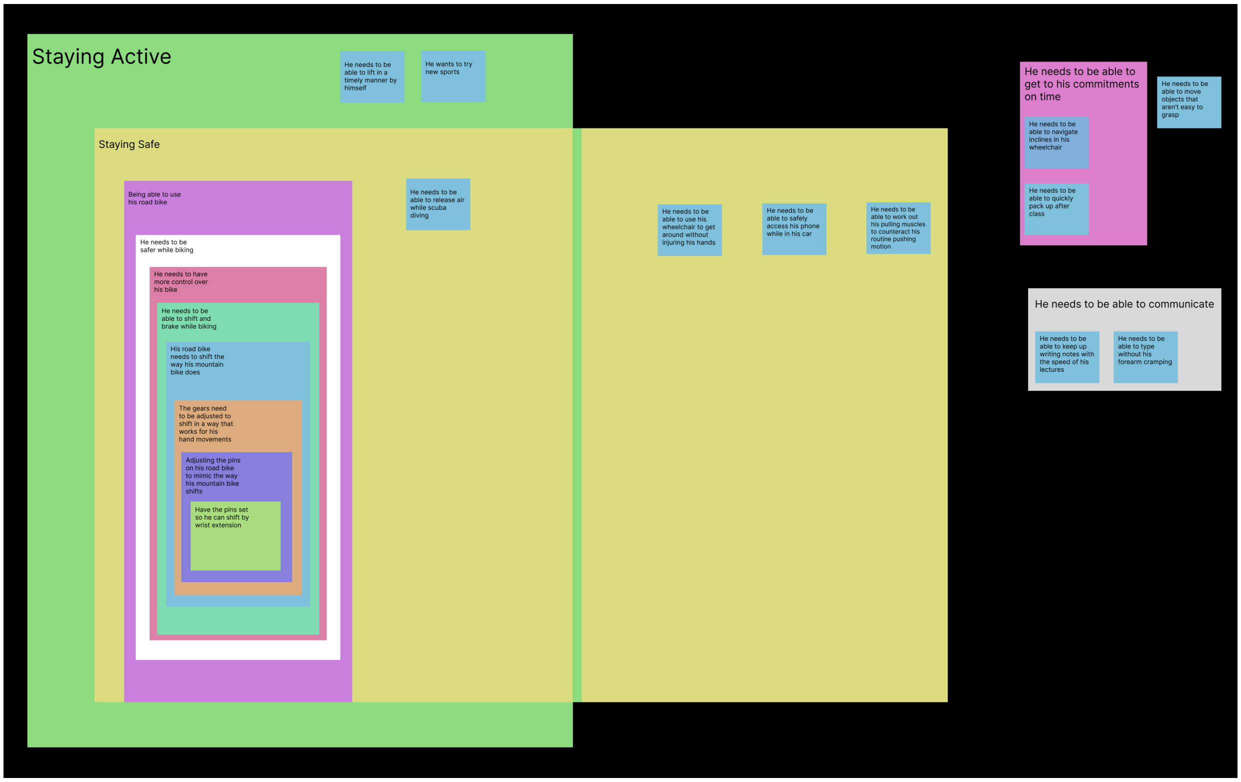

Fig. 7: Full Hierarchical Need-Knower Chart

Fig. 8: Quadgrip Bike Mechanics by BikeOn

Item No.	Item	Quantity
1	Adjustable Arm	2
2	Offset Plate	2
3	Brake Connector Plate	1
4	Shifter Connector Plate	1
5	1.5" bolt	8
6	1" bolt	7
7	Lock Nut	15
8	Lock Washer	15

Fig. 9: Bill of Materials