UW Adapted Fitness: Grip Strength Improvement Mechanism

Preliminary Report

BME 200/300

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Abstract

Grip Strength is a vital indicator of overall muscle function. It is essential for daily activities and maintaining independence. As humans age, grip strength naturally declines. Additionally, individuals recovering from stroke or traumatic brain injuries often experience impaired control and precision in their grip motion. This project aims to design and fabricate a safe, affordable, and user-friendly, device that assists with both hand flexion and extension while improving grip strength over time. This device targets older adults and rehabilitation patients who seek to regain full function in their hand. After evaluating three design concepts, the final design consists of a half glove made from a modified work glove, fitted with 3D printed rings made out of TPU. Bungee cords connect the rings to a 3D printed central connector via small metal S hooks and metal washers. This allows customizable tension levels to change between different hand strengths while maintaining simplicity and reliability without complex electronics. The glove is secured with an adjustable Velcro wrist strap and can be worn independently by the user. Prototype testing assessed the range of motion, comfort, amplification, adjustability, safety, and durability. Preliminary designs indicated the glove effectively supports finger extension and allows for independent use, depending on the individual’s range of motion in their opposite hand. This device demonstrates strong potential as a low-cost, low-profile rehabilitation tool for hemiplegic patients. Future work will include further testing bands of varying elasticity and tension, adding a wrist splint to the glove for increased stability and surface area, and adding an adjustable winding knob on the back of the glove.

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Introduction

Grip strength devices are necessary in today's society to help strengthen the overall hand muscles in human beings. Grip strength is such an imperative part of human life and is used in everyday functions to get humans through simple daily tasks. Our device targets the demographics of older men and women, as it is common for grip strength to decrease as humans age [1]. Grip strength affects the muscle function throughout the entire body, so it is important that grip strength stays strong throughout a human's life. Additionally, our device targets rehabilitation patients recovering from a stroke or any traumatic brain injury. Control and precision grip force are impaired in people with a traumatic brain injury [2]. They can relearn the motions of extending their hand by repeating the motion several times. Our device will allow these patients to relearn the motion of extending their hand from a closed fist.

Several grip strength mechanisms are currently available on the market. At the UW Adapted Fitness Center, the primary grip device that is being used is called Active Hands [3]. This device straps a patient's hand to a machine or weight and enables them to have a stable and controlled grip. The device acts as a glove, fastening around the wrist, over the fingertips, and around the object using Velcro straps. Active Hands is used in patients who have disabilities or are practicing rehabilitation of their grip flexion, facilitating the relearning of proper gripping motions. Another current grip mechanism being used is a grip trainer [4]. This device is a spring hand gripper, centered around a central spring that provides resistance when the user squeezes inward on two metal or plastic handles. The resistance serves to strengthen the hand, fingers, and forearm muscles. The device is commonly used for rehabilitation, improving grip strength, flexion, and enhancing hand endurance. A more experimental design is a robotic hand. This design targets hand extension rather than flexion. In this system, the patient inserts the hand into a glove while maintaining a fist position. The device is powered by a motor to extend the hand from a balled position to an extended position [5]. There are wires down the fingers of the hand to pull the hand open, and it is powered by a battery, a control board, and a motor.

Some individuals who face challenges with grip strength that limit their ability to perform daily tasks and participate in exercise are clients of the UW Adapted Fitness program. Current tools in the Conway Adapted Fitness space are not tailored to our clients' needs, creating a gap in training effectiveness and slowing their path to rehabilitation [2]. This project aims to design a safe, affordable, and user-friendly mechanism to support targeted flexion grip training, improve independence, and enhance the client's overall fitness experience.

Figure [1]: Active Hands grip mechanism used at the UW adapted fitness center [3]

Figure [2]: Grip trainer used at the UW adapted fitness center [4]

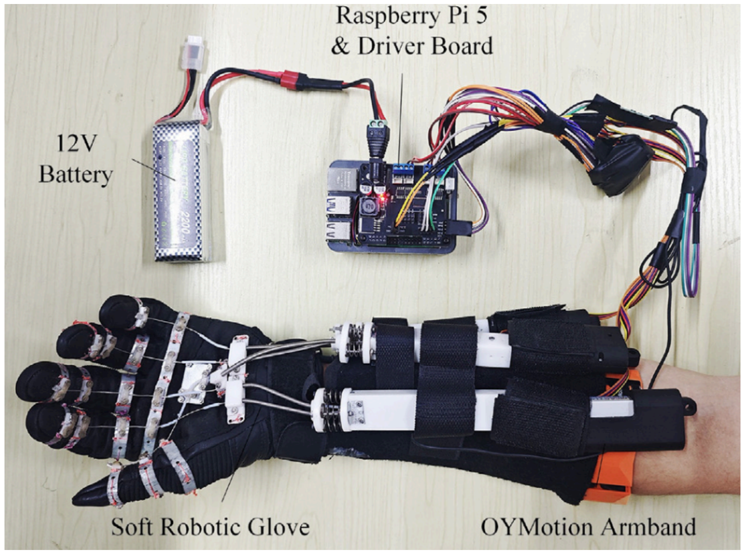


Figure [3]: Soft robotic glove to test grip strength [5]

Background

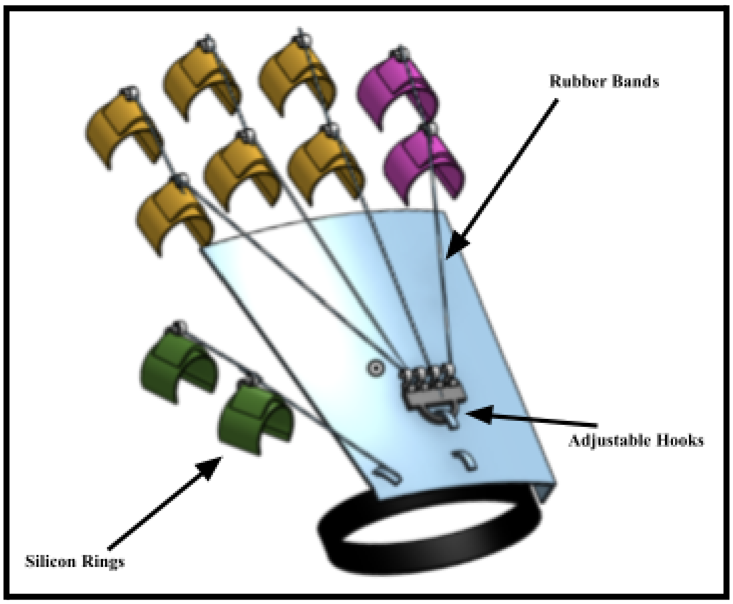
The skeletal muscles are what cause movement in the human body. The muscles that control grip strength specifically are in the forearm of the body [6]. Specifically, the anterior division of forearm muscles plays the most important part in flexing joints. Two muscles in the hand that play a key role in grip strength are the flexor carpi radialis, which flexes the hand and fingers, and the flexor carpi ulnaris flexes, which adducts the hand. These are two muscles that are extremely involved in grip strength and function [7]. Additionally, the extensor digitorum supercialis is the main muscle that specifically targets the extension of the hand, which is the main muscle target of our project. All of these muscles travel down the forearm and onto the hand, and are not solely muscles just in the hand. The muscles that are extrinsic to the forearm are what control most of the grip strength in the human hand. However, our design does not target these muscles because the radial nerve, which controls hand extension, is what has been most affected by our client's traumatic brain injury. Our team met with an occupational therapist who specializes in hands, and she emphasized that our design should focus on the extensor digitorum supercialis, or the muscles in the back of the hand, because of the nature of our client's injury.

When researching for this project, our team began by expanding our knowledge of the human hand's anatomy to better understand how to approach creating a device that focuses on the flexion and extension of the hand muscles. After we had a better grasp of the anatomy, we moved on to understanding how strokes and traumatic brain injuries present in patients, and also their path to recovery. We researched both strokes and TBIs because they present very similarly to one another, and there is far more literature on stroke rehabilitation. We also researched competing designs to gauge the other products available to consumers. This allowed us to figure out what worked well and what did not, and apply those findings to our final design. Now that we have chosen our final design, we have turned our attention to researching sweat-resistant biomaterials that can be easily sanitized. The device must also be lightweight and provide as much comfort to the client as possible.

Our client was a professional skier before he suffered a traumatic brain injury, resulting in him being hemiplegic (having paralysis or weakness) on the right side of his body. The resting state of his right hand is currently a fist, and the goal of our design is to work on opening his hand about 180 degrees and to over time, be able to fully open his hand to assist him if he falls and would need to get back to his feet by himself.

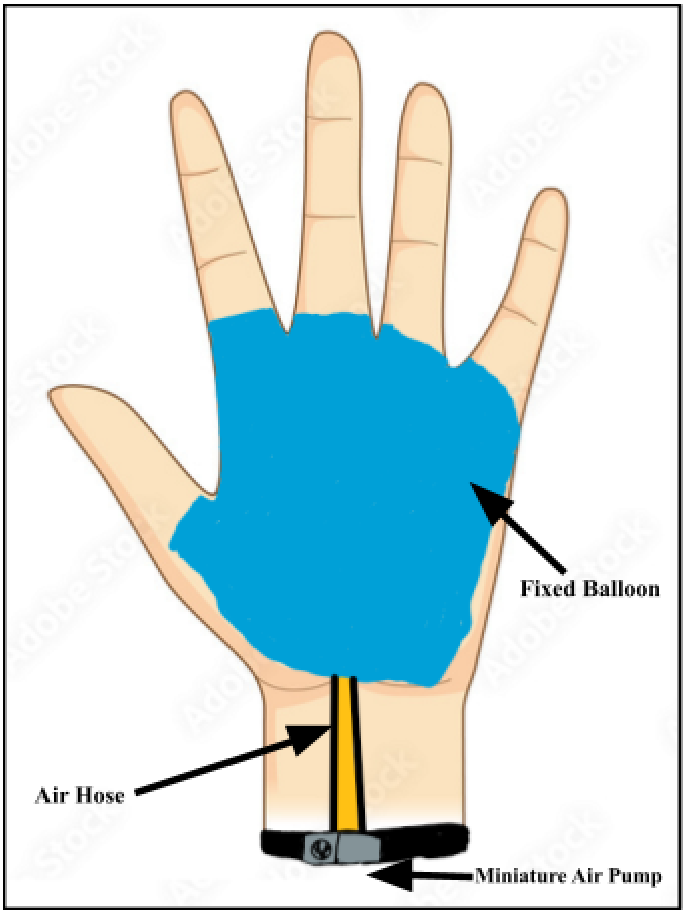
The client's requirements for the device were that it must be easy to put on, it must be adjustable and comfortable for the skin, it must allow quick and safe release of objects in case of emergency, and it must be easy to sanitize for frequent use. With these criteria in mind, we began to formulate design ideas to best meet the specific needs of our client. (See full PDS in Appendix 1)

Preliminary Design



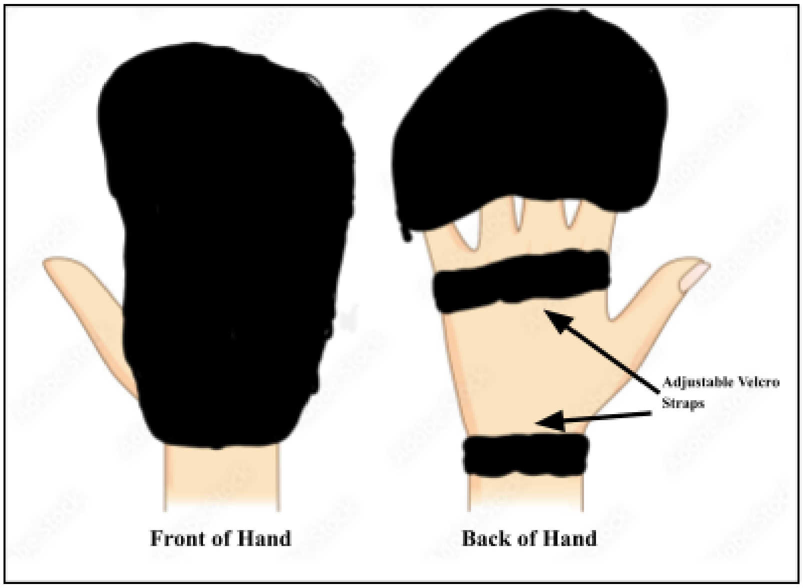
Hooks & Bands

This design utilizes a system of high tension elastic bands to assist with hand extension by gently pulling the fingers back into an open position. Each band provides controlled resistance and is hooked at a central connection point located on the back of the hand. When the central point is pulled backward, the tension in the bands increases, extending the fingers outward from a clenched position. The central connector can then be hooked onto the back of the glove to maintain the hand in an open configuration, allowing the user to rest without actively exerting force. The elastic bands are attached to open silicone rings that fit around each finger. The rings are designed with a small gap that allows them to be slipped onto the user's fingers without requiring the hand to be opened first, an essential feature for patients with limited finger mobility due to stroke or neurological impairment. The open ring structure provides both stability and ease of use while distributing tension evenly along the fingers to prevent discomfort.



Balloon Glove

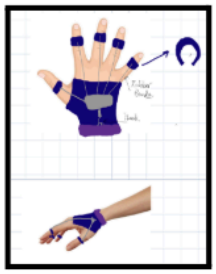
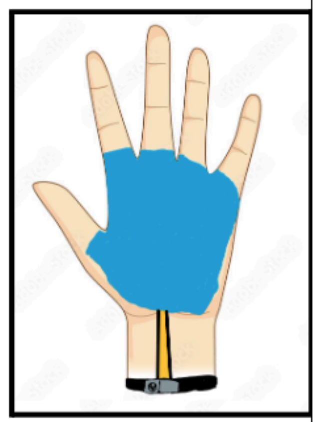
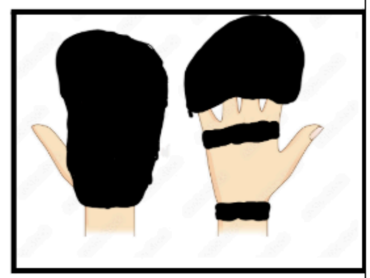
This design uses a deflated balloon shaped like the lower section of the hand. The way this device would open the hand is by inflating the balloon to expand outwards from the palm and push against the inner surface of the fingers which will cause the hand to open from its original clenched position. The balloon component would be fixed to the palm of the glove and secured using rubber clips inside the gloves lining. This positioning would ensure that the balloon maintained the correct shape and orientation while it is inflated, to attempt to mimic natural finger motion. Airflow would be controlled by an air hose that connects the air balloon to a compact electric pump that would be located on the Velcro wrist strap. This creates an overall, lightweight and portable solution with this device.



Hinge Mitten

This design focuses on the user's hand enclosed within a soft, supportive mitten structure that helps maintain alignment and comfort during operation. The mitten is secured with an adjustable strap that runs over the top of the hand and wrist, ensuring the hand remains properly positioned throughout motion of the hinge. Beneath the palm of the hand lies a mechanical hinge mechanism that begins in a closed, locked position when the device is at rest. In this starting state, the user's hand naturally wraps around the hinge in a fist like posture, mirroring the hand's natural resting grip. The hinge is electronically connected to a compact power source along with a simple control board that regulates the motion sequence. When activated, the hinge mechanism is powered to extend and "snap open," converting stored mechanical energy into motion that gently pushes the fingers outward. This controlled movement transitions the user's hand from a clenched fist to an open, extended position of about 180 degrees.

Preliminary Design Evaluation

		Design 1: Hooks & Bands		Design 2: Balloon Glove		Design 3: Hinge Mitten	
							
Criteria	**Weight**	Score (Max 5)	Weighted Score	Score (Max 5)	Weighted Score	Score (Max 5)	Weighted Score
Range of Motion	25	5	25	2	10	3	15
Patient Comfort	25	2	10	3	15	4	20
Amplification	20	4	16	2	8	2	8
Adjustability	15	3	9	4	12	4	12
Safety	10	3	6	5	10	4	8
Cost	5	4	4	2	2	3	3
Total	**100**	70		57		66	

Range of Motion:

One of the most important criteria for this project is the maximum Range of Motion that can be accomplished with the design. In this context, the Range of Motion criteria refers to the maximum angle that is formed from the knuckle bone of the finger to the tip of the finger to test the flexibility of each device. The Range of Motion is important to the device because it will assist us in evaluating the effectiveness of each design. For this reason, Range of Motion is weighted 25/100 in our design matrix, as it directly reflects the design ability to meet core goals of the project.

The Hooks & Bands design scored a 5 out of 5. The range of motion that is provided with each band with the ability to increase the tension by using the hooks greatly puts this design above the rest. The mobility of each ring being attached to each individual finger allows for much more range of motion which adds to this design.

The Balloon Glove scored a 2 out of 5. The design uses an inflating balloon to initially get the hand to an open position but after fully expanded, the user's hand will not be able to reach the maximum range of motion. In addition, it may raise the fingers unevenly, further limiting flexibility.

The Hinge Mitten scored a 3 out of 5. By using a flat hinge, it moves the entire hand and fingers upward together, achieving an open-hand position. However, this design only allows motion in one direction and prevents natural gaps from forming between the fingers, limiting its overall flexibility.

Patient Comfort:

Patient comfort is very important to this project as it is being designed to improve the quality of life of a specific patient. The final product should be comfortable enough that the patient actually wants to use it frequently. Comfort is a difficult quality to quantify, especially since we do not know the exact materials we are using yet. Comfort is weighted at 25/100

We rated the Hooks & Bands design a 2 out of 5. The high tension bands could cause some discomfort by pulling the glove and the patient's wrist forward. The glove will most likely have to be made of some hard material like plastic in order to hold the bands with tension. This can be adjusted for with padding underneath but still gives this design a low patient comfort rating.

The Balloon Glove design was rated a 3 out of 5 for patient comfort. This design does not open the hand all the way, this would most likely be more comfortable for the patient, but it does sacrifice functionality. The balloon glove would fit to the patient's hand slowly as the balloon expands. The wrist device that inflates the balloon would be somewhat heavy and uncomfortable so this design was rated as our middle comfort option.

The Hinge Mitten design received the highest comfort rating of 4 out of 5. This design would open slowly and evenly which would be very comfortable for the patient. The design does not require the patient to put on a glove like the other two designs, this is important since the patient cannot open their hand unassisted. The mitten would also be padded on the top to provide more comfort to the patient. The only reason this design is not rated a 5 is because the patient must grip the mitten by opening their hand slightly.

Amplification:

Refers to how effectively the device multiplies a small input (like a pull, inflation, or hinge motion) into a larger, useful opening movement of the patient's fingers. Since the patient has limited voluntary motion, the device must provide mechanical or powered assistance to amplify that motion into meaningful finger extension. Amplification was weighted 20/100.

The Hooks & Bands design scored a 4 out of 5. The high-tension elastic bands provide strong amplification because a small amount of pulling force translates into significant finger extension. This makes it highly effective at magnifying limited input into large finger movements. However, the strong forces may feel uncomfortable or unnatural if not carefully tuned.

The Balloon Glove design scored a 2 out of 5. The inflatable balloon gradually pushes the hand open, but the amplification is weak since most of the "input" comes from the balloon expansion itself rather than a small motion being multiplied. The effect is more gentle and progressive, but it doesn't provide a powerful amplification of motion.

The Hinge Mitten design scored a 2 out of 5. The hinge mechanism is powered electronically, so the "amplification" is not mechanical but rather dependent on the motor/hinge. It can open the hand, but the movement is more of a direct action rather than an amplification of a small patient input. Because of this, the score is lower than Hooks & Bands.

Adjustability:

Another important criteria for the project is the adjustability of our design. This criteria refers to the ability of our design to fit users that are not our client and work easily for hands that are bigger or smaller. Aspects that affect the adjustability include the flexibility of materials that we use and if the size is adjustable. Adjustability is important because if our design works well for our client, it has the potential to work well for other TBI and stroke patients that are hemiplegic. However, the focus of this project is on helping our specific client, which is why we have Adjustability weighted 15/100.

We rated the Hooks & Bands design a 3 out of 5 because while the rubber bands are flexible, we were concerned that the rings that go around the client's fingers are a specific size. On smaller hands, the rings would simply slip off and be useless, while on larger hands the rings wouldn't even be able to be put on.

We rated the Balloon Glove design a 4 out of 5 because it is a pretty adjustable design. The glove that we plan to pair with the balloon would be attached to the wrist with Velcro, meaning that it would be able to fit on hands of all sizes. Additionally, the balloon is able to be blown up as much or as little as needed, which also helps with adjustability.

Finally, we rated Hinge Mitten a 4 out of 5 as well. We discussed the similarities between the Hinge Mitten and a tool used for a large number of clients in UW Adapted Health that allows stroke patients to grip rehab machines. It is another adjustable design because it utilizes Velcro and a design less tailored to a specific person because it is larger and would work on hands of different sizes.

Safety:

Another key factor to this project is the safety of the design for the patient. This criteria means that the design will be safe for the patient to use and protect the user from any further injuries that could result from the design itself. This criteria is important because we want the patient to be able to use the mechanism comfortably without the worry or risk of further injury. The area of focus for this project is the hand, which has many sensitive tensions and ligaments. It is imperative that our design isn't too powerful where it rips or tears any of the muscles in the hand, and it is comfortable on the user's hand without any sharp edges. Since the safety of the design is necessary for success, we rated it a 10/100.

We rated The Hooks & Bands design a 3 out of 5 for safety because some of the features of the design have room for potential injury. For instance, rubber bands have the potential to snap if they have too much stretch and tension. If this occurred, the bands would snap onto the patient's hand resulting in potential injury. Additionally, the hooks added onto the fingers of the base would most likely be made out of metal. If metal is not sawed down and smoothed, it has the potential to be sharp which would be harmful to the patient. Because of these two features of the design, we ranked it a 3 out of 5.

We ranked The Balloon Glove design a 5 out of 5 for safety because there are few features that would cause this design to be unsafe. The design would be centered around a balloon or inflatable object, which is a squishy and comfortable feature. Additionally, we would use Velcro to attach the balloon to the hand, which is a material that is extremely safe and comfortable.

Lastly, we ranked The Hinge Mittens a 4 out of 5 because the design is relatively safe but has a few features that could be slightly risky. The mitten and strap over the top of the hand is extremely safe and will be made out of safe and comfortable material. However, the hinge could be slightly unsafe because it will be snapped upward electronically. We need to make sure that the hinge doesn't have too much power and open snap too quickly. This could result in the hyperextension of the finger. However, once we complete many tests and find the right amount of energy needed, the design will be extremely safe.

Cost:

In all designs, minimizing cost is always a goal. For this project, the budget is currently unknown but ensuring the cost is as low as possible makes the device more inclusive for many groups. Though cost is important to the design, it is not a core goal which is why it is weighted 5/100.

The Hooks & Bands scored a 4 out of 5. This is because the cost of the hooks are quite minimal as well as the rubber bands that will be holding most of the design together. A glove will also be modified to fit the main part of the hand which will have little cost all together.

The Balloon Glove scored a 2 out of 5. Sourcing a balloon of the correct size and shape could be more costly, and the miniature air pump required adds a significant expense compared to other designs.

The Hinge Mitten scored a 3 out of 5. Its main components are a glove with Velcro and a denser hinge material. While not overly expensive, the hinge makes it slightly more costly than the Hooks & Bands design.

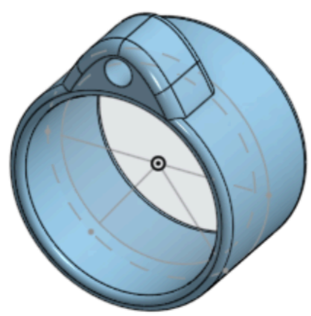
Preliminary Final Design

Out of our three options the Hook and Bands design had the highest overall score of 70. This design performs well in the range of motion, amplification and cost categories, which are all very important to this project. Ultimately we choose this design because of its simplicity and effectiveness when it comes to amplification. The changeable rubber bands allow this design to be easily modified for different hand strengths and the lack of complex electronics makes the glove more intuitive for the client to use and less prone to failure. The client will be able to put on the glove unassisted using the overhand glove design and open rings. This would not be possible for the other designs. We currently have rough dimensions of the client's hand that we are using for the size of the glove and rings. The glove will be 6.5 cm wide and 12 cm long. The thumb ring will have a circumference of 5.4 cm, the index, middle and ring finger rings will have a circumference of 5.5 cm and the pinky ring will be 6.5 cm. The wrist band circumference will be 17.5 cm. The rubber bands will reach from the center of the hand to the bottom segment of each finger and shorter bands will reach from the bottom segment to the middle segment.

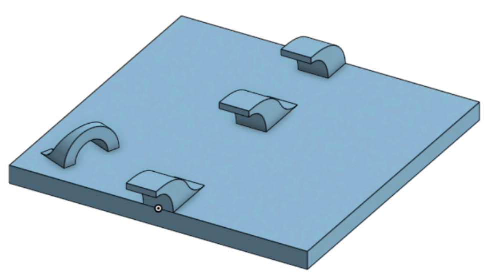
Fabrication

Materials

The half glove is made using a work glove, this soft material allowed us to easily cut the glove into the shape we needed and is comfortable for the client, while still being stiff enough to not be pulled forward by the bands. We 3D printed rings made of Thermoplastic Polyurethane (TPU), a very flexible and durable plastic. This will allow them to slip on over the fingers with relative ease and comfort, while not easily coming off when the bands pull at them at an angle. We decided to use bungee cords to provide the force to pull the fingers open. The bungee cords are attached to the rings using small metal s-hooks. The bungee cords attach to a central connector that we printed out of Polylactic Acid (PLA), a stiffer plastic. The bungee cords are attached to the connector using washers. A flat plate (also printed from PLA) is embedded in the fabric of the glove. This plate has three hooks poking through the glove. The connector can be pulled back and hooked on to pull the fingers back.



Figure[8]: Proximal ring



Figure[9]: Plate with hooks

Methods

1. 3D Modeling: The hook connector, backplate and rings are modeled in OnShape. The hook connector and backplate are printed out of PLA while the rings are printed out of TPU.
2. 3D Printing: Printing with TPU gave us some difficulties as its flexibility made it prone to stringing and rarely printed exactly how we wanted it to. In order to fix this we had to ensure there were no floating sections on our parts, as supports do not print well when using TPU. After the rings were printed we also had to sand them to get rid of imperfections and make them more comfortable. The PLA prints were much easier to work with and we did not have to change our models to account for any issues.
3. The Half Glove: We used a right-handed work glove as the base for our prototype. The fingers cut off so that there is only one hole that the fingers (excluding the thumb) all go through a single hole. The glove we used had a hook and loop wrist strap that we did not remove.
4. Hand Hooks: The glove has multiple layers of fabric, we cut it open and slid the plate in between them. Once the plate was between the fabric we cut slits for each of the 3 hooks. After this we used a needle and thread to sew the gap closed and secure the plate in place.
5. Hooks and Bands: The rings all have a hole with a diameter of 3 mm to fit the s hooks. The bungee cords are looped at the end to attach to the other end of the hooks.

Figure[10]: Work gloves with hook and loop wrist strap

Final Prototype

Our final prototype consists of a work glove with all of the fingers cut off that has a Velcro strap to secure the glove to the wrist. Inside of the glove we hand sew our 3D printed backplate in place by inserting it in between two layers of fabric on the top side of the glove. The four hooks on the backplate protrude through the top side of the glove through small holes that we created. There are three hook settings used for the pointer, middle, ring, and pinky fingers, and one hook setting used separately for the thumb. The three hook settings allow the client to move the bungee cords back to provide more tension in a rehabilitation setting. The thumb has a separate hook setting as it needs to be moved in a different direction due to the positioning of the tendons in the thumb. A 3D printed connector is used to attach our bungee cords all onto the same central connect to allow them to attach to the three hook settings together. The bungee cords are attached to the connector by 4 washers, which extend upwards to our 3D printed rings. We created five 3D printed rings made of our TPU that are individually connected to the bungee cords by s hooks. The bungee extends down to the 3D connector for the pointer, middle, rings, and pinky. The thumb has a separate connector on the backplate. The design has multiple settings to allow for varying difficulty in a therapy environment.

Our client starts by putting the glove on his hand. Once the glove is in place, the 5 rings are slipped onto the fingers past the knuckles. The 3D connector can be attached to the first hook setting that provides the least amount of tension and acts as a rest position. Once the client gets comfortable with this amount of tension, we can move the setting back to provide more tension. This can be repeated again for the 3rd setting to provide the most amount of tension in the bungee cords, which helps extend the client's hand outward. The client can repeat these motions for as long as desired to help his brain get used to the motion of extending the hand open. The repetition of this motion will be extremely beneficial for the client to help his brain remember these steps and muscles used.

Figure [11]: Two parts of final prototype

Figure [12]: Final prototype on hand

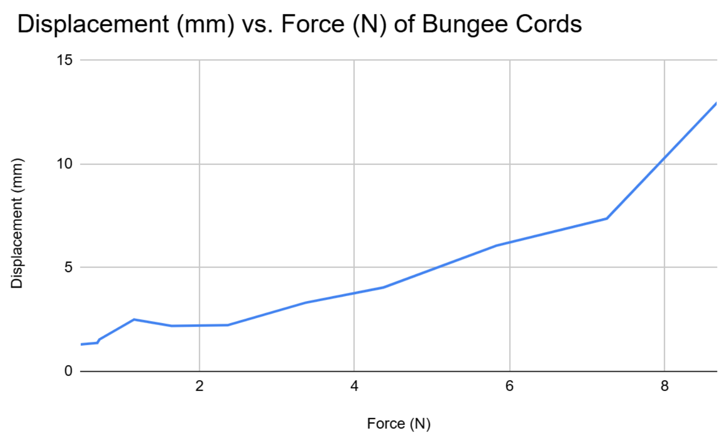
Testing and Results

The prototype will be tested across several key criteria, including range of motion, comfort, amplification, adjustability, safety, and durability. We tested our prototype by using it ourselves as well as bringing it to frequent client meetings. Our client tried many iterations of our product and we gathered their feedback to make changes. Most of these changes involved making the prototype more usable and comfortable. The glove was also fitted to hands of varying sizes, demonstrating adequate adjustability, though finger ring sizing posed a limitation. Safety was assessed through over-stretching and cycling of the elastic bands, which revealed no immediate hazards, while durability tests involve repeated open-and-close motions, indicating that the prototype can withstand repeated use without loss of function.

We tested the elasticity of our bungee cords by using Hooke's Law. By attaching weights to our cords and measuring the displacement we can get a force value. By setting this force equal to the force on the object caused by gravity. By averaging out these values given several different weights we determined the k value of the bungee cord is 0.75 N/m. This value can be used to determine how far the bungee cord needs to be stretched to provide a specific force. If we had more time for testing we would test the force required to open our client's hand and use the k value to calculate the distance we would need to stretch the bungee to achieve this.

Mass (g)	Starting Length (mm)	Final Length (mm)	Displacement (mm)	F (N)	K (N/m)
46.8	62.19	63.49	1.3	0.459108	0.35316
69.2	62.19	63.56	1.37	0.678852	0.4955124088
72.14	62.19	63.73	1.54	0.7076934	0.4595411688
117.58	62.19	64.69	2.5	1.1534598	0.46138392
167.15	62.19	64.38	2.19	1.6397415	0.748740411
240.87	62.19	64.42	2.23	2.3629347	1.059611973
342.83	62.19	65.5	3.31	3.3631623	1.016061118
445.81	62.19	66.24	4.05	4.3733961	1.079850889
594.29	62.19	68.26	6.07	5.8299849	0.9604587974
739.43	62.19	69.56	7.37	7.2538083	0.9842345047
884.58	62.19	75.16	12.97	8.6777298	0.6690616654
				Average K Value:	0.7534197142

Figure[13]: Elasticity Test Table



Figure[14]: Displacement (mm) vs. Force (N) Graph

Discussion

The Hooks & Bands glove demonstrated that a lightweight, low-cost assistive device can meaningfully support finger extension for individuals with hemiplegia. Compared with earlier design concepts and similar low-profile orthotic devices reported in existing rehabilitation literature, this prototype achieved a larger range of motion while maintaining adjustability and user comfort. These findings suggest that simple mechanical systems, when properly tuned, can offer functional benefits comparable to more complex robotic gloves, particularly for users who need accessible, low-maintenance solutions. The amplification tests will further clarify the device's effectiveness by determining whether minimal input tension can translate into clinically meaningful finger extension, an important consideration noted in prior soft-robotic research.

Several ethical considerations guided both the testing process and the intended use of the device. All comfort and usability testing was performed in a manner that avoided undue strain, irritation, or risk to participants, and user feedback was prioritized when refining materials and tension levels. In its real-world application, the device must prevent injury, avoid excessive joint stress, and allow the user full autonomy over engagement and disengagement. Addressing material durability, such as preventing rubber band snapping and ensuring that the glove does not create harmful pressure points are essential ethical concern, particularly when used by individuals with reduced sensation or impaired motor control.

Evaluation results led to several important design changes. Initial prototypes using rubber bands did not provide adequate extension force, motivating the exploration of alternative materials. Testing bungee cords of varying lengths revealed that they offered significantly greater and more consistent tension, enabling the design to be simplified from two rings per finger to one. Braided nylon string, although elastic, lacked sufficient stiffness and was therefore discarded. User comfort assessments also highlighted the need for additional padding and potentially softer or medical-grade elastic materials to reduce localized pressure. These modifications will improve both safety and long-term wearability.

Despite promising results, several sources of error may influence the interpretation of the findings. Force measurements were approximate and limited by the sensitivity of the tools available, introducing uncertainty into the estimated tension-to-extension relationship. The small sample size restricts generalizability, and user feedback may not capture the full range of clinical variability seen in hemiplegic populations. Additionally, the prototype does not yet support finger flexion, which may be necessary for more comprehensive rehabilitation; this limitation could influence user satisfaction scores and functional outcomes.

Overall, the Hooks & Bands glove demonstrates strong potential as an accessible, low-cost alternative to high-tech assistive gloves. With continued refinement, particularly in material selection, padding, long-term durability, and measurement precision, the device could serve as a practical tool for supporting hand rehabilitation and daily functional tasks in individuals with hemiplegia.

Conclusions

The client requested a device to assist in the rehabilitation process of strengthening the muscles and prevention of calcification in the joints of the knuckle with opening the hand. The final design consists of 3D printed rings that slide onto the client's fingers. From the rings, bungee cords of similar length and elasticity attach from the rings and meet in the center of the hand on a plastic connector. The connector is then able to hook onto different hooks of varying distance from the fingers, which provides an assistive force that pulls the bungee cords and helps open the hand. The rings allow the device to be put on without the client's hand being forcibly opened by sliding onto each finger. The printed rings and backing connector are easy to disinfect and the adjustability of the design will allow the client to be comfortable during rehabilitation.

Our future work will focus on increasing the tension provided by the bungee cords to apply more force to each finger from a stable position. This would be done by cutting the cords with a sharp tool evenly across each cord and then securing a small metal o-ring onto the end and tightening with a tool and a loop for the s-hook to attach to, similar to how they were provided when ordered. This would allow the client's hand to extend further open from a fist, allowing the design to be more effective and helpful in a rehabilitation setting. Additional future work includes a redesign of the hooking mechanism. Instead of hooks that require an extra hand to adjust the tension, an adjustable knob that can be twisted to increase and decrease the tension of the cord would be much more effective and requires less hands and assistance to use. This would require many changes to how the current bungee cords are tightened and possibly a change in cord for a thinner cord. Some extra improvements could be found in completing a design that encompasses the thumb of the hand to further improve overall mobility. This would be done by attaching more support on the back of the thumb along the joint to assist with extension and eventually the opening of the hand. Another direction would be to create a splint-like device that goes around the wrist and extends up the arm to give full support to the bungee cords compared to the plastic backing on the current design. This splint does have the downside of becoming too rigid and making the wrist area too stiff.

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Appendix

Appendix I: Product Design Specifications

Function

The device must assist the user with impaired hand function by enhancing their ability to open and close the hand with greater strength and control. It should assist to initiate movement when needed and resistance to build muscle strength during rehabilitation. The device should promote dexterity, independence in daily activities, and measurable progress in grip strength over time.

Client requirements

- The device must be easy to put on and remove.
- Adjustable to fit different hand sizes and grip requirements.
- Must allow safe and quick release of objects in case of emergency.
- Must be easy to sanitize for frequent use

Design requirements

1. **Physical and Operational Characteristics**
    a. **Performance requirements**
        i. The most important performance requirement of the device is to improve the client's grip strength, the goal being to achieve full strength after having suffered a traumatic brain injury.
        ii. The device must also be easy to take on and off without assistance.
        iii. Must transmit and store grip strength information to track the progress of the client over time.
    b. **Safety**
        i. The device must be made with materials that do not irritate the skin, and fit comfortably on the hand
        ii. Must allow for quick release of objects in case of emergency
    c. **Accuracy and Reliability**
        i. Device must be versatile and allow the user to perform multiple tasks with objects of different sizes and shapes
        ii. Device must report feedback accurately and consistently, allowing the client to understand progress or setbacks in their grip strength training
    d. **Life in Service**
        i. The device should be reliable for at least one year with regular use. Components should be replaceable for ease of repair.

e. **Shelf Life**
    i. The lifespans of any sensors or electronics used should be considered
    ii. If a battery is required it should be replaceable and removable for storage
f. **Operating Environmen**t
    i. Product will be used in a gym during workouts/physical therapy sessions
    ii. Durability should reflect this: sweat-proof, breathable, flexible
g. **Ergonomics**
    i. Glove should be comfortable for the client to wear when working out
    ii. The glove needs to be put on by a person with limited hand mobility
h. **Size**
    i. The device should be around the size of the client's hand. The device will need to cover up to the fingertips of the hand and around the palm of the hand.
    ii. The average size of a male hand is length of about 7.6 inches and a width of 3.5 inches so our design will be in similar dimensions.
i. **Weight**
    i. The weight of our object should be light and should not put an immense amount of pressure on the client's hand. The client has mobility issues with extending his hand, so the object can't be too heavy because that would make it extremely difficult for the client to learn how to use the tool.
j. **Materials**
    i. The materials that we choose to use will have to be comfortable and durable. The client will have to wear this product while working out and potentially for everyday use, so it is necessary that it is comfortable material. The materials will also have to withstand and last during strenuous activities.
    ii. There will also need to be a power source so materials like batteries and wires will be necessary so the object can move and pull the hand open.
k. **Aesthetics, Appearance, and Finish**
    i. The product will be worn frequently, so it should be clean and have good aesthetics. Additionally, it should not have anything sharp or unsafe protruding for the device because the client could get injured. Objects like wires and batteries should not be shown on the device and should be concealed appropriately.

2. **Production Characteristics**
    a. **Quantity**
        i. Only one final device will be needed to be fabricated with the option of being scalable for mass production.
    b. **Target Product Cost**
        i. Current competing devices range from $90 to $400. Low cost materials and modular design should be implemented to reduce replacement costs.
3. **Miscellaneous**
    a. **Standards and Specifications**
        i. The device must adhere to basic safety and usability standards for assistive and fitness devices, prioritizing user comfort, ergonomics, and injury prevention. Where applicable,

guidelines from the Americans with Disabilities Act (ADA) and ASTM standards for fitness equipment will be referenced. The mechanism should also follow university safety protocols for electronics and mechanical design.[1]

b. **Customer**

   i. The primary customer is Dr. Kecia Doyle, representing UW Adapted Fitness. The client is a longtime Adapted Fitness participant with a specific need for grip strength improvement in one hand. The device should be tailored to his abilities, preferences, and fitness goals, while also providing value for broader adapted fitness applications.[update when we meet John(patient)]

c. **Patient-related concerns**

   i. The client's comfort, safety, and motivation are central to the design. The mechanism must not cause pain, strain, or unintended injury during use. Ease of use, adjustability, and the ability to operate independently (when possible) should be taken into consideration. The design should accommodate variability in grip strength and hand dexterity.[update when we meet John(patient)]

d. **Competition**

   i. Commercial grip-strength trainers exist (spring-loaded hand grippers, therapy putty, squeeze balls), but they are not customized for adapted fitness clients with asymmetric grip ability or integration into workout routines[2]

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Appendix II: Expense Table

Item	Description	Manufacturer	Mft Pt#	Vendor	Vendor Cat#	Date	QTY	Cost Each	Total
Category									
Rubber Bands	Used to model the tendons in the hand and provide enough tension to pull the hand from a fist.	Staples	28611-CC	Staples	143297	10/8/2025	1	$5.79	$5.79
S Hooks	Used to attach the bungee cords to the 3D printed TPU	Grainger	U17380.000.0075	Grainger	2ZDK2	10/8/2025	1	$4.39	$4.39

	rings								
Glove	Base of our design to embrace the hand	Grainger	902L	Grainger	26H497	10/8/2025	1	$19.99	$19.99
3D Printed TPU Rings	TPURingers for the joints of the hand	Wendt Commons		Wendt Commons		10/17/2025	15	n/a	$5.79
3D Printed Hook backing	Connecting center to attach bungee to different settings to pull back hand	Wendt Commons		Wendt Commons		10/8/2025	3	n/a	$1.31
3D Printed Bungee Center	Attach four bungees together	Wendt Commons		Wendt Commons		10/8/2025	3	n/a	$1.06
Heat Shrink Tubing	Used to attach the rubber hands to the S hooks for our first design idea	Grainger	CPO18 706	Grainger	3KH56	10/8/2025	1	$15.51	$15.51
Washers	Attach the bungees to the 3D printed band center	Wendt Commons		Wendt Commons		11/10/2025	10	$0.125	$1.00
Fishing Line	Used as a potential idea to model the tendons of the hand and provide tension to open the hand	Fastenal	39-250 W	Fastenal	921715 807	11/10/25	1	$14.22	$14.22
Bungee	Used to model the tendons of the hand and open the hand from a fist	ECB		ECB		11/10/25	1	free	
								TOTAL:	**$69.06**

Appendix III: Fabrication Procedure:

1. Measure our client's hand for sizes of each of his knuckles.
2. 3D print the hand rings out of TPU using the size measurements of the knuckles of the client.
3. 3D prints our bungee center and our hook backing.
4. Cut the fingers off of our athletic glove.

5. Mark the size of location on the glove of where our 3D printed hook backing will be.
6. Using scissors, cut out a slit inside the two layers of fabric in the glove where the top of the hand would be located the size of our 3D printed hook backing.
7. Slip in the hook backing and cut holes on the top of the glove for the hooks to poke through.
8. Hand sew the slit opening so the hook backing is securely stored in the glove
9. Poke holes into the top of our 5 3D printed TPU rings to fit the S hooks inside
10. Insert the S hooks in the holes of the rings
11. Using a dremel, cut the metal wrapped wire off of our 5 smallest bungee cords.
12. Attach the 5 bungee cords onto the S hooks with the knot opening on the top of them.
13. Using pliers, open the small washers we purchased to attach the other side of the 4 bungee cords.
14. Insert the bungee cords into the small washers and attach this at once to the 3D printed bungee connector.
15. Close the washers using pliers to securely fasten to bungees onto the connector.
16. Repeat this step for all four of the bungee cords so they are all attached to the connector.
17. The connector can then be attached to the hook backing on the glove, completing the fabrication process of our design.

Appendix IV: Testing Protocol:

Required equipment: Scale, attachment hooks, weights of varying masses (50g-1000g), ruler, bungee cord, calculator

Steps:

1. Place the weight on the scale to measure its exact mass. Weigh the hooks used for attachment. Add these masses together and record the value.

2. Calculate the force caused by acceleration of gravity using the formula F=ma where a=9.81. Record this force.
3. Use the ruler to measure the starting length of the bungee that is being tested, record this value.
4. Attach the weight to the bungee cord and hang it over a ledge so that the weight is suspended in the air without touching any walls.
5. Use the ruler to measure the new length of the bungee cord, record this value.
6. Calculate the displacement (x) by subtracting the initial length from the final length.
7. Calculate the spring constant (k) of the band by using the equation k=x/F where x is the displacement and F is the force calculated in step 2.
8. Repeat steps 1-7 for each weight.
9. Average the calculated k values.