The Bear Paw: A Quick-Release Wearable Device to Assist Transmetacarpal Amputees

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Abstract

In the United States, limb loss is a problem for many people with amputation, with a large portion of amputees recieving amputation of the fingers and hands. One common form of hand amputation used to remove damaged fingers is called transmetacarpal amputation. Transmetacarpal amputation is the full removal of the proximal, middle, and distal phalanxes above the hand metacarpals. In this report, our team addresses the needs of an individual who has experienced transmetacarpal amputation of digits 2, 3, 4, and 5 by creating an assistive technology (AT) device for this person. This hand worn device, called the Bear Paw, can quickly and easily attach and remove a variety of tools for user-specific applications. Examples of tools created to be fully compatible with this device include a passive hook for carrying heavy bags, a grip to attach to golf clubs for golfing, and a button actuated and electronically powered robotic finger. Using these tools, the user can perform a variety of actions that are usually more difficult to perform without the Bear Paw system. In future steps, the team proposes conducting user and strength testing of the current attachments to assess the device's performance and user experience. The team hypothesizes that people with transmetacarpal amputation will prefer an adaptable, easy to use, and quick release system (like the Bear Paw) in comparison to traditional assistive technology devices. Furthermore, the team would like to explore additional applications for the development of new quick-release attachments by conducting further interviews and surveys. Not only can this novel device improve the quality of life of those with amputation, but it can also help researchers explore how traditional assistive technology devices compare to lightweight and cost effective devices like the Bear Paw.

I. Introduction

In the United States alone, there are almost 2 million people living with limb loss, and nearly 465,000 of these individuals have lost fingers to amputation [1] [2]. For those who require finger amputation, one specific type of amputation that removes the majority of a person's finger is a transmetacarpal amputation. A transmetacarpal amputation is defined as being the removal of the distal and proximal phalanges of the finger while maintaining the majority of the person's palm. This type of amputation is not as common as some other forms of amputation such as transtibial or transfemoral amputations, but it still affects a large number of individuals in the United States. With the loss of fingers, transmetacarpal amputees lose the ability to perform dexterous manipulation with their affected hand, which in turn provides these individuals with numerous challenges when needing to grasp and carry objects. The purpose of this study was to learn about the challenges associated with transmetacarpal amputation and what types of assistive technology devices can be developed to overcome these challenges.

A. Background

Assistive devices have long existed for transmetacarpal amputation and similar injuries. The implementation of prosthetic devices into a user's life might include a steep learning curve; however, the consistent use of prosthetic devices contributes to the improvement of health and quality of life of amputated individuals [3]. Despite the benefits, the documented rates for people with amputations show that many of them do not consistently use prosthetic devices; the usage rates of prosthetics vary between 27-56% for upper-limb amputation individuals and 49-95% for lower-limb amputation individuals [4]. These rates also indicate that individuals with upper-limb amputations are less likely to consistently utilize a prosthetic device compared to lower limb amputees. Some potential reasons for this disparity include the historically devices' limitation to restoring total hand functionality, or injuries to the non-dominant hand, which is the case of the team's need-knower. Furthermore, despite the advancements in prosthetic engineering, a recent survey carried out by the American Association for Hand Surgery (AAHS) revealed that around 76% of hand surgeons do not work in interdisciplinary teams that include hand surgeons, physical medicine and rehabilitation physicians, or upper extremity prosthetists, and only a minority of the hand surgeons interviewed are familiarized with prostheses for digital, transmetacarpal, or thumb amputations, which also contributes to the low usage rates of such devices [3].

Current state of the art categorizes prosthetic devices into the following three groups: passive functional, body-powered, and externally powered prostheses [3]. Passive prosthetics can be static or adjustable and they are utilized by one out of three individuals with limb amputations [5]. One of the simplest yet effective passive devices is the basic hook. Hook orthotics at the hand can aid particularly with coarse power manipulations such as carrying objects with handles. Passive positionable devices offer a greater range of utility being able to adjust the grip for each task, although they might require the use of the opposing hand or other objects to change or release the grip.

Body-powered devices go a step further and allow for control of hooks or other terminal devices by the movement of the shoulder or wrist with action transmitted by harness and cable setups. These can be somewhat bulky and less intuitive. Body-powered prosthetics are usually composed of a control tension cable, joint (such as a mechanical hook), and socket [6].

Externally powered prosthetics have two types of control systems; myoelectric and electric switch [7]. Limited myoelectric prosthetics are available as well which allow for more independently controlled alterations of grips. Experimental uses of myoelectrics have utilized a range of control signal methods including muscle contraction or arm, wrist, and toe movement.

Comparing body-powered and externally powered assistive devices, there are benefits and downsides to each of these types of systems. Body-powered devices tend to be cheaper with simpler designs than externally powered prosthetics, while externally powered prosthetics are more expensive and possess more complex designs. However, externally powered prosthetics tend to have a higher degree of precision when compared to body-powered prosthetics. In this project, our team aims to incorporate the benefits of both passive functional and externally powered designs in order to help those with transmetacarpal amputation.

B. Overview

In this report, Section II consists of the preliminary data that was acquired from the team's interview with a person with transmetacarpal amputation. Section III introduces the methods used by the team in the design process of the Bear Paw system, as well as the future steps the team plans to take in order to pursue further device testing and human subjects research. This section is followed by Section IV, which describes the intellectual significance of the work completed by the team and how the Bear Paw device contributes to the current body of knowledge. The final section is Section V, where the importance of the broader impact of this device is explained. This section conveys how this device can be made available to those with transmetacarpal amputation, as well as those who wish to manufacture the device for others. Appendices A through C provide in-depth analysis of other useful information that provide insight to the research performed, information about the need-knower/user's needs, and the design process behind the device itself.

II. Preliminary results

The team proceeded to interview a transmetacarpal amputee about their daily life and any challenges that they experience as a result of their condition. The interview was conducted via the zoom meeting platform application with teammates contributing as interviewers and note-takers during the hour and 15 minute meeting. From the interview, preliminary results were obtained to determine the problem area for our need-knower and provide the team with targeted needs to address. To begin with, the team learned that the right hand of the need-knower is fully functional and is used for the majority of dexterous manipulation tasks. However, the need-knower's left hand has digits 2, 3, 4, and 5 amputated, leaving the need-knower with only a thumb on the left hand. When the amputation took place, additional surgery was performed to repair the damaged thumb which resulted in the metacarpophalangeal (MCP) joint and proximal interphalangeal (PCP) joint becoming fused together. This surgery allowed the need-knower to close the thumb farther across the palm of the hand to provide a power grip. However, this power-grip has very limited use for the need-knower, since this grip causes strain on the thumb and is discomforting. The team took note of this specific orientation of the left hand when moving into the user needs analysis portion of the interview process. Observing the interview notes, the team came away with three primary user needs to address in a possible design (shown in Table 1 below). The full table displaying the top five user needs that were observed from the interview can be found in Appendix B.

Primary Needs	
Hold heavy objects	• Comfortable attachment • Comfortable for longer periods of time • Can survive heavy use
Use heavy tools	• Swing objects like baseball bats, golf clubs, axes, wrenches, etc. • Prevent slipping of hand from heavy tools • Have a similar dexterity to the function of the little and ring fingers
Wants to comfortably excel at golf	• A device that helps grip the golf club consistently providing enough force and lateral traction during a complete golf swing • Increase rotational traction on golf club • Allows for consistent placement of the hands on the club • Flexible enough grip to be able to follow through the swing of the golf club • A device that alleviates forearm strain/pain after playing for a long time

TABLE I: *Primary needs identified during interview.*

The first of these needs was that the user wanted to hold and carry heavy objects with his affected hand. During the interview, the interviewee continuously referred to the task of needing to carry objects like groceries on a daily basis but only being able to do so with one hand. This revealed a problem area to the team and was deemed a problem that a potential solution could be developed for. The second identified need was that the user wanted to be able to hold and use different tools with their affected hand. At several moments during the interview, the need-knower mentioned the desire to be able to possess a power grip while holding different objects with their amputated hand. Th need-knower described that their thumb on the affected hand had fused joints which prevented the ability to form a powerful grip, so this led to the establishment of the second need. The third need that was observed by the team was that the user wanted to be able to excel at the game of golf, but was prevented from obtaining this need due to their affected appendage. In addition to these three primary needs, the need-knower also explained their vision of a device that could act as a quick connect tool that allows someone to use a set of specialized tools. In this design, the user could select a specific tool that could be quickly attached and removed from a connector that was on the user's hand. Through the observation of these needs and ideas, the team decided to focus on a solution that could uniquely combine these top three needs and the multi-tool idea in order to develop a prototype that would successfully satisfy the need-knower.

III. Methods

We have created a quick changing modular assistive device for transmetacarpal amputees. The base device straps onto the user's palm, wrist and distal forearm. It is made from a hard material (currently

PLA) that is sewn into the straps in an ”I” shaped design as seen in Figure 2. Custom attachments for various use cases can then be slid onto the the base of the device as seen in Figure 3. The base provides resistance to forces in all axis directions except for the proximal or distal directions. The user has the ability to pick the orientation in which to slide the attachment onto the base: either sliding it on in the proximal or in the distal direction. Moreover, the team predicts that this loading capability will be strong and reliable across many applications, while also being easy to remove when needed. Because of the modularity and the ease of changing attachments, this single device is capable for aiding in a wide range of use cases. Currently we have developed a simple hook attachment, an attachment to aid the user excel during a golf swing, and a motorized claw device that is operated with a button. The simple hook is designed to carry heavy items with handles such as groceries and bags. This attachment can be seen in Figure 4. The golf swing attachment allows the user to keep the golf club in place to increase driving accuracy and distance, it can be seen in Figure 5. The externally powered design (motorized claw) has additional attachment points to assist with grasping and gripping. The claw and the controlling button attach to the straps on the user’s palm by Velcro. The device is composed of two static fingers working with an actuated one with the aim of grasping and gripping a multitude of objects. The electrical circuit powering the device is also attached by Velcro to the forearm. The user can close the grip by pressing the button. Pressing the button again releases the grip. The device is controlled by an Arduino Nano Every and the action is accomplished by a small servo motor that closes the actuated finger. The externally powered device attachment is shown in Figure **??**. Figure 1 shows the state transition diagram for operation of the motorized claw.

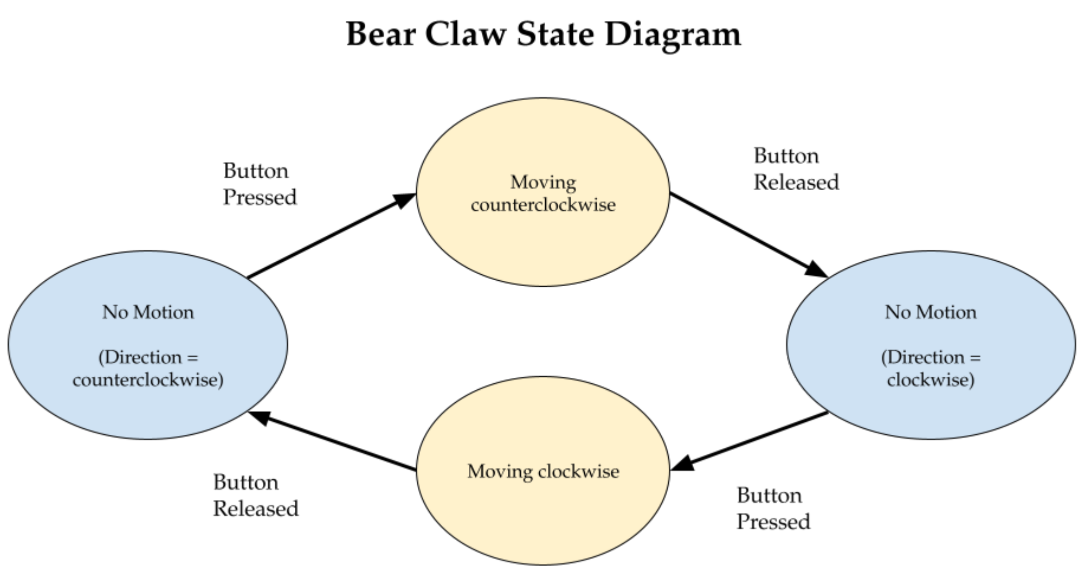

Fig. 1: *State transition diagram for operation of the externally powered design (motorized claw).*

With the device complete, the team has proposed future work to be pursued in order to further iterate the device design and improve the device for real-world applications. A short list of proposed steps to be taken by the team is recorded below.

To create future iterations of the device, the team proposes to:

1) Conduct user testing of the current device
2) Strength test the current device and attachments
3) Determine additional use cases by additional interviews and surveys

Our hypothesis is that if this device is used by a transmetacarpal amputee who consistently uses a prosthetic device, and the user performs a variety of different actions with the Bear Paw while equipping different tools/attachments, then the user will prefer to use a quick-release tool system like the Bear Paw instead their current AT device. In order to test this hypothesis, the team would plan to recruit about 20 people with transmetacarpal amputation who use an AT device on a daily basis to assess the Bear Paw's usability, user experience, usage successful rates compared to their existing device, and potential shortcomings of the current device. During this study, the team would have each subject stand by a table that has a 10 different objects on it. These objects would vary in size, shape, and weight. The subject would then proceed to attach their own traditional body/externally-powered device to their hand, which they would use to attempt to grab/lift the objects up and hold each object for 10 seconds. After performing the test with their own device, the subject would attach the quick-release Bear Paw prototype that the team has developed and use a variety of attachments to lift and hold the objects. Each of the Bear Paw attachments provided would be made specifically to lift one of the presented objects. This study directly tracks and compares the user's performance when using their own AT device and the Bear Paw device. If the subject fails to pick up the object with the device in use, a score of 0 is recorded. If the subject can lift the object up but not hold it for 10 seconds, a score of 0.5 is recorded. If the subject successfully lifts and holds the object for 10 seconds, a score of 1 is recorded. At the end of each test (for the user's own device and the Bear Paw), the scores will be added up to track which device performs best. Following this, the user will then provide written feedback about the test and will record whether or not they prefer the Bear Paw quick-release tool system over their own AT device. This study will allow the team to learn more about the Bear Paw's performance and how its product performance and user satisfaction can be improved.

In the event that the team's hypothesis is false from subject tests, the team could investigate why the Bear Paw system is not performing to the intended standard. This would include following up the subject tests with interviews with the study participants to ask what makes the interviewee's current AT device more beneficial for use when compared to the Bear Paw system.

In order to perform human subject tests, a protocol will need to be submitted for review through the Internal Review Board (IRB) for the Protection of Human Subjects. The team plans to submit a protocol that outlines the purpose/objective of the proposed study, the methods that would be used, how the data would be managed/analyzed, and how the respect of person's would be adhered to. Any possible ethical issues would be addressed in this protocol as well. Additionally, all members of the engineering team have completed their CITI Group 1: Biomedical Research Investigators Training as of May 2022.

In addition to conducting user tests, the team plans to strength test the device and its attachments when grasping and lifting objects. The main strength tests of the device would be to attach the Bear Paw and its attachments to the hand of a user and then perform tension and compression tests. A load would get attached to the device and pull downward (tension) and weights would be added until device failure (cracking or full fracture). Following this, the device would push against a force sensor (compression) until failure, and the failure force would be recorded. This type of testing technique would be useful to determine the mechanical limits of the device and its attachments. In future iterations of the device, we intend to use stronger materials for the base device and attachments to increase mechanical performance. Particularly for heavy lifting tasks such as pull-ups, we would like to use carbon fiber or steel. When using the Bear Claw system, the externally powered finger will use motors with higher torque and will also feature a locking ratchet mechanism such that the grip placement is secure.

Another step the team would like to take is to reach out to more people with transmetacarpal amputation to conduct more interviews/surveys. This Spring, the team was only able to interview a person with transmetacarpal amputation on only one hand, and this need-knower also only possesses a thumb on the affected hand. As a result, it would be beneficial to the team to speak with people who have different digits amputated on their hands to learn more about the challenges people with transmetacarpal amputation face. This could aid in the team's iteration process of the current Bear Paw system and could give the team a different point-of-view of the challenges that result from hand amputations. The team would plan to send surveys out to people with transmetacarpal amputation in order to better understand their daily routine, commonly encountered challenges, and potential areas that new attachments could be developed for the Bear Paw device.

IV. Intellectual Merit

Through the creation of the Bear Paw device and the testing of its performance, contributions to the current body of knowledge and influence on other researchers' work in the area of transmetacarpal amputation will be made. The novel part of this design process is that the team has developed a quick-release system that has an infinite number of applications. Not only can this device be used for carrying heavy bags, golfing, and grasping rounded/random objects, but this device also serves as the foundation for a limitless number of attachments that can be paired with the Bear Paw. Using the same securement mechanism for newly created tools, users of the Bear Paw can attach a variety of new attachments to fit their user-specific needs. If the hypothesis being tested is found to be true (people with transmetacarpal amputation prefer a quick-release system like the Bear Paw), then this means that the development of prosthetic devices with the ability to quickly and easily swap out tools for attachment might be more useful than traditional prosthetic systems. Future studies might include comparisons of many different quick-connect AT devices for transmetacarpal amputees and how likely users are to consistently use these novel devices on a daily basis. If it is determined that the hypothesis in this study is false, then the team could focus on making improvements to the current quick-release system for future subject testing and to validate the hypothesis.

V. Broader Impact

The motivation behind the development of the proposed device is to create an affordable solution that can be replicated by people with no engineering background. The hope is that the engineering design plans of this project can be made open sourced to the transmetacarpal amputee community so that people can either make this device for their own use or have others create the product for them. For example, a well known volunteering organization that helps amputees called e-NABLE can pair amputees with people who can 3D print and design affordable assistive technology devices for their own use. This device could be published on e-NABLE's Devices Catalog so that anyone in the future could download the prototype designs, build the device, and see how impactful it can be in their lives. Not only would this device directly impact the person who would use it, but posting a device design like this as an open source can show other assistive technology designers new ideas of how to create AT for people in need. In addition, this could help e-NABLE volunteers form meaningful connections with one another as well as the people who receive these assistive technology devices.

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Appendix A
Discovery Decomposition

Topic of the interview: everyday manual activities for people with missing digits.

1) Restoring form and function to the partial hand amputee: prosthetic options from the fingertip to the palm: [3].

- Background/Hypothesis: Discusses types of specific prostheses used to restore form and function to a person's hand(s) as well as rehabilitation methods.
- Methods: Explores the passive, body-powered, and externally powered prostheses for a variety of different finger amputations.
- Results: Prosthetic hands for partial hand amputees bring significant aid to amputees.
- Conclusion: It is more beneficial to partial hand amputees to build them a prosthetic device that is very good at one specific task than trying to make one that can perform many tasks.
- Test Hypothesis: Partial hand amputees will prefer prostheses that are very good at one function rather than decent at many functions.

2) Painful and Nonpainful Phantom and Stump Sensations in Acute Traumatic Amputees: [8].

- Background/Hypothesis: Phantom limb pain of traumatic upper limb amputees was investigated to determine the presence and frequency of postamputation sensations.
- Methods: Sixty-five out of ninety-six patients returned a questionnaire evaluating the following questions: side, date, extension, and cause of amputation; preamputation pain; and presence or absence of phantom and stump pain, phantom and stump sensations or both.
- Results: The prevalence of phantom pain was 44.6%, phantom sensation 53.8%, stump pain 61.5%, and stump sensation 78.5%. Only 3 (5%) of 65 amputees indicated that they have neither painful nor nonpainful sensations.
- Conclusion: The study concluded the existence of two peaks of first appearance of phantom and stump phenomena were noticed: an early peak immediately after amputation, a second peak 12 months after amputation or later.
- Test Hypothesis: The presence of postamputation sensation or pain has a time-dependent correlation.

3) The effect of grip position on golf driving accuracy and distance: [9].

- Background/Hypothesis: The grip position (GP) in golf affects performance results in terms of shot accuracy and hitting distance but it is unknown which specific GP are optimal for better outcomes.
- Methods: This study collected data of 28 amateur recreational golfers and investigated the impact on driving accuracy and distance of 5 manipulated GPs using increments of 15º between strong (-30º) and weak (+30º).
- Results: Neutral and stronger GPs generated the best driving accuracy and distance while weaker GPs showed significantly more unfavorable accuracy and distance effects.
- Conclusion: The results of the study suggest asymmetric outcome effects of symmetrical GP manipulation, with a more optimal performance for neutral and stronger grips.
- Test Hypothesis: Adapting the GP suggests practical implications that coaches can use to improve the total driving performance of golf players.

4) Development of a grip aid system using air cylinders: [10].

- Background/Hypothesis: Development of a small and lightweight grip aid system using air cylinders to assist people who have weak grasping force for daily living activities.
- Methods: Grasping force and finger trajectories of able subjects were analyzed to design the assistive device. Furthermore, the grasping ability of the system was measured by grasping different objects with the device attached to a wooden hand model.

- Results: The study indicated that the system mounted to the wooden hand was able to assist the grasping of objects despite some limitations due to the non-elastic properties of the wooden material.
- Conclusion: This grip aid system showed the ability to assist grasping of a wide variety of objects confirming the usefulness of the system.
- Test Hypothesis: The device seemed to be successful in grasping assisting activities.

5) Evaluation of Load Distributions and Contact Areas in 4 Common Grip Types Used in Daily Living Activities: [11].

- Background/Hypothesis: Determination of the load distribution (LD) and contact area (CA) size of the palmar surface of the hand during 4 common grip types.
- Methods: Eighty healthy subjects participated in the study utilizing the Grip system which was made by a special glove comprised of different sensor areas that collected LD and CA percentages by performing different grip patterns.
- Results: The CA percentage of the thumb was maximum for all grip patterns, whereas the LD percentage of the index finger was highest for pinch, lateral, and tripod grip patterns. In standard grip, the percentage of LD was almost same for the thumb and index fingers.
- Conclusion: The study showed that the LD and CA patterns differed widely amongst standard, pinch, lateral, and tripod grip patterns. Furthermore, the percentage of CA occurring in the thumb was highest in all grip types.
- Test Hypothesis: LD and CA percentages depend on grip pattern.

6) Quantitative functional evaluation of a 3D–printed silicone-embedded prosthesis for partial hand amputation: A case report: [12].

- Background/Hypothesis: Analysis of a body powered 3D printed prostheses for partial hand amputees.
- Methods: Uses molds and computed tomographic scans of a partial hand amputee patient's hand in order to create a matching prosthesis using CAD software followed by fabrication using 3D printing techniques.
- Results: Comparing two different types of prostheses (one a complex prostheses, the other a simplified version), the patient had a higher satisfaction rating using the simpler version.
- Conclusion: A simpler designed mechanism is more likely to be adopted by the partial hand amputee rather than a sophisticated and more complex mechanical mechanism.
- Test Hypothesis: The patient will prefer a prosthetic design that is more sophisticated.

7) 3D-printed custom-designed prostheses for partial hand amputation: Mechanical challenges still exist: [13].

- Background/Hypothesis: Technical study and comparison of two 3D-printed prosthetic prototypes for a partial hand amputee.
- Methods: This study uses a 2-year long iterative design process that compares two prosthetic devices in the areas of grip strength, dexterity, and consumer perceptions/feedback.
- Results: The participant in the study reported that both devices lacked adequate grip strength but comparable dexterity when compared to myoelectric prostheses.
- Conclusion: This paper agrees with prior work that 3D printed prostheses tend to lack the production of grip/pinch forces that are desired of partial hand amputees.
- Test Hypothesis: One of the proposed 3D printed prosthetic designs will yield higher user satisfaction than usual prostheses on the market (compared to iLimb).

8) NOVEL MECHANICAL FINGER PROSTHESES: [14].

- Background/Hypothesis: Provides an overview of the need for mechanical finger prostheses for individuals with partial hand amputations.

- Methods: Introduces readers to understanding the problem for partial hand amputees, what current solutions exist, outcomes from research, and how amputees can obtain these prosthetic devices.
- Results: Using user feedback tests such as the Quick-DASH (Disability of Arm, Shoulder, and Hand), engineers can learn how effective prosthetic solutions are for partial hand amputees, with results showing that the majority of amputees only continually use prostheses if they meet the user's intended functionality.
- Conclusion: Body powered prostheses are more likely to be used by working-class individuals due to their simpler design when compared to more advanced electronic designs.
- Test Hypothesis: People who possess manual labor jobs will fail to return to their line of work after a partial hand amputation unless they possess a simple prosthetic device to replace their hand's functionality.

9) Affordable passive 3D-printed prosthesis for persons with partial hand amputation: [15].

- Background/Hypothesis: This study aims to provide a simple and affordable prosthetic hand design that can be used by individuals in developing countries.
- Methods: Using the dimensions of a transmetacarpal amputee's hand, a passive body powered prosthetic device was developed and tested using quantitative and qualitative assessments.
- Results: From the variety of tests performed by the patient with the device, it was evident that the prosthesis was deemed lightweight and very good at performing grasp stability.
- Conclusion: Though the prosthetic device met the user's needs, the device is limited in it's performance due to the fact that it needs to use the contralateral hand to achieve grasping and low grasping strength.
- Test Hypothesis: Partial hand amputee's with limited resources will be satisfied with the performance of a prosthetic hand that only weighs 100g and costs less than 20 USD to create.

10) Is it Finger or Wrist Dexterity That is missing with Current Hand Prostheses?: [16].

- Background/Hypothesis: Current advanced prosthetic are limited in their degree of freedom which causes users to compensate by making unnatural movements with their arms and body. This can cause undo stress and pain. This study aims to find whether this can be addressed by focusing on increasing wrist or finger dexterity.
- Methods: Right-handed subjects with fully functioning hands were asked to complete tasks while wearing devices that restricted various types of hand movements. The efficiency, and quality of the motions were then recorded.
- Results: From the variety of tests involving limiting the wrist and the fingers in different ways, the efficiently of tasks decreased the most when limiting the fingers. Additionally, more compensating movements were made with finger limitations.
- Conclusion: Although both the wrist and fingers play an important role, for daily tasks the dexterity of the fingers played a more important role.
- Test Hypothesis: Limiting finger dexterity decreases efficiency of tasks and greater alterations of natural movement as compared to limiting wrist dexterity.

11) Prosthetic rehabilitation of a patient with finger amputation using silicone material: [17].

- Background/Hypothesis: Finger prostheses pose unique challenges in both their function and aesthetic. Typically a remaining partial finger is used for attaching prostheses. This study aimed to create an alternative retention method for patients without finger remnants.
- Methods: A 28-year-old man with a totally amputated ring finger from a traumatic injury was used as the case study. The group group created a finger that was retained by extending the prosthesis to palmar.

- Results: The prosthetic was functional and more aesthetically pleasing to the patient as compared to their previous prosthetic.
- Conclusion: The proposed prosthetic met the need.
- Test Hypothesis: A more aesthetically pleasing complete finger prosthetic can be achieved by retaining a silicon prosthetic on the palm.

12) Soft and tissue repair of the hand and digital reconstruction: [18].

- Background/Hypothesis: This article reviews current methods for finger reconstruction and soft tissue repair in the hand.
- Methods: The article graphically illustrates finger injuries and the methods for their resolution. There is a focus on the thumb reconstruction.
- Results: There are many methods for repairing tissue after traumatic injuries.
- Conclusion: Ideally patients have should be restored to at least their thumb and two fingers.
- Test Hypothesis: Surgical repair of fingers can be successfully accomplished using a variety of methods depending on the nature of the injury and what the priority is for the patient.

13) Decoding of human hand actions to handle missing limbs in neuroprosthetics: [19].

- Background/Hypothesis: The researchers aimed to find better techniques for gaining quantitative data on natural hand motion. They seek to use this information to create improved predictions and reconstruction of the action missing fingers for the application of prosthetics.
- Methods: Subjects were asked to repeatedly complete common tasks while wearing a CyberGlove that contains sensors for 18 degrees of freedom. This data was then processed and analyzed for use in predictions.
- Results: Natural hand motion is highly variable. However, the initial moments of the motion were more clearly defined and were distinct enough for use in predictions as well as in some cases of reconstruction of missing fingers. The reconstruction was most accurate for the middle and ring fingers.
- Conclusion: These methods could greatly help with the advancement of ”smart” prosthetics such that intended actions could be predicted based in initial hand gestures and the movement of remaining fingers.
- Test Hypothesis: Intended grasps and finger motions can be predicted using either initial hand motions or surrounding fingers.

14) Silicone finger prosthesis with customized ring wire loop substructure as a retentive aid: [20].

- Background/Hypothesis: Retention of prosthetics is a continuing problem. The anatomy of the retention site is specific to the person. The study aims to provide another method for retention that is cost effective, simple, and customizable to the individual.
- Methods: The device was created for a 23-year-old male with a partially absent middle finger on the right hand due to a snake bite. The retention system was made from a stainless steel ring that would slip onto the finger remnant.
- Results: The prosthetic fit as intended.
- Conclusion: The design is simple and easily customizable. The form factor is minimal making it more aesthetically pleasing than some alternatives.
- Test Hypothesis: The device enables the effective and customized retention of a prosthetic finger.

Appendix B
User Needs Breakdown

Primary Needs	
Hold heavy objects	• Comfortable attachment • Comfortable for longer periods of time • Can survive heavy use
Use heavy tools	• Swing objects like baseball bats, golf clubs, axes, wrenches, etc. • Prevent slipping of hand from heavy tools • Have a similar dexterity to the function of the little and ring fingers
Wants to comfortably excel at golf	• A device that helps grip the golf club consistently providing enough force and lateral traction during a complete golf swing • Increase rotational traction on golf club • Allows for consistent placement of the hands on the club • Flexible enough grip to be able to follow through the swing of the golf club • A device that alleviates forearm strain/pain after playing for a long time
Wants to safely ride a mountain bike	• A device that helps secure the affected hand to a mountain bike handlebar as the user is riding the bike • Will release the hand from the handlebar in the event the user need to let-go
Wants to look natural	• Wants a device that is visually appealing to the eyes • Does not want to be looked at strangely by strangers • Does not want to attract a lot of attention • Wants a device with a sleek design

TABLE II: *Primary needs identified during interview*

Appendix C
Investigational Device Details

You will put the details of your investigational device here.

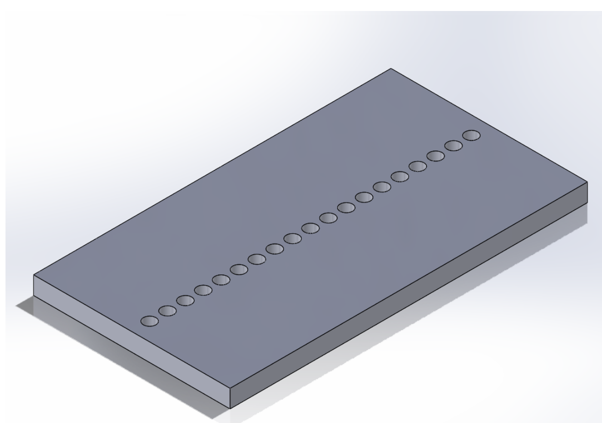

Fig. 2: *Base of device that is sewn onto the hand straps*

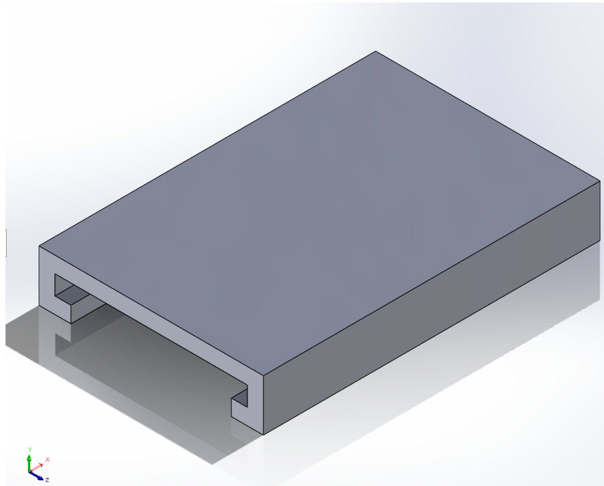

Fig. 3: *Blank attachment that is slid over the base*

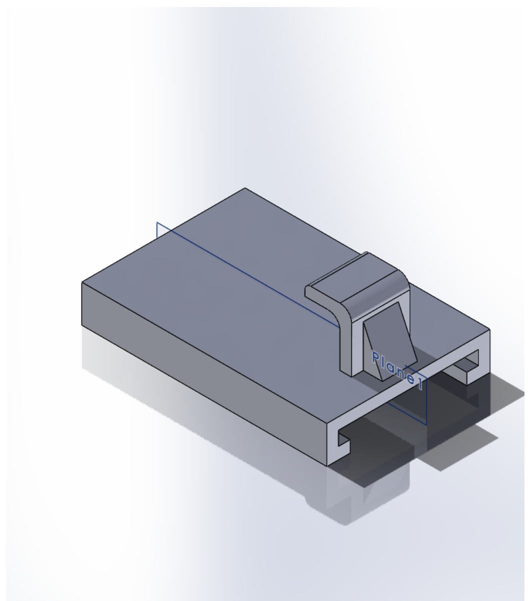

Fig. 4: *Basic hook attachment*

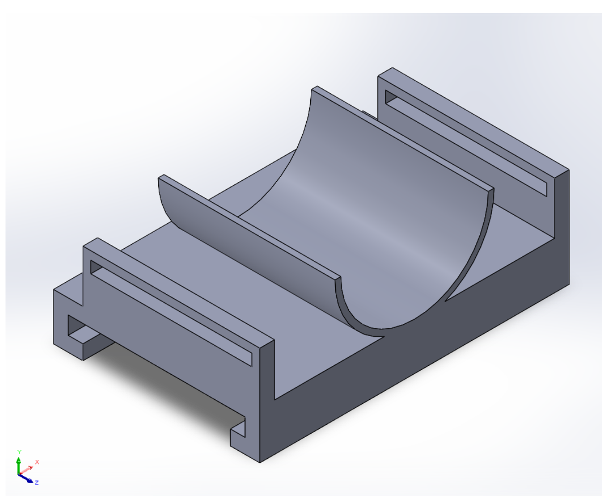

Fig. 5: *Plastic part of golf club gripping attachment, A strap secures the club.*

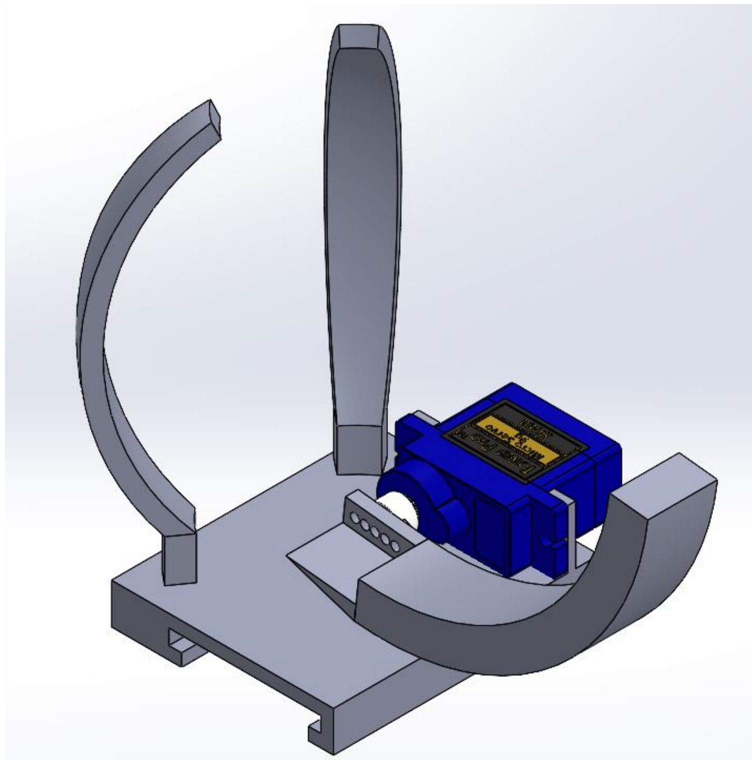

Fig. 6: *Full Bear Claw mechanism with the motor, final claw, and static claws.*

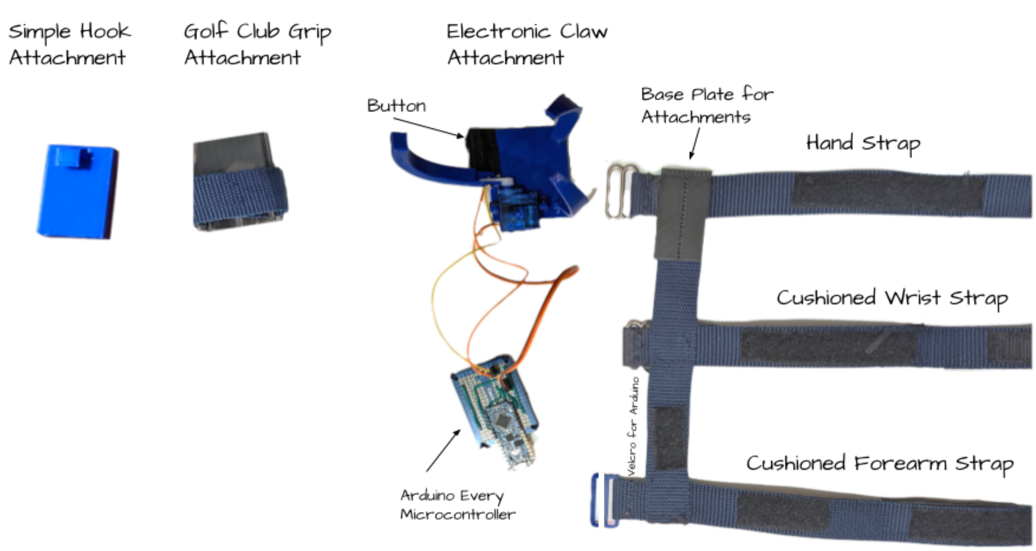

Fig. 7: *Full device showing the hand straps and the three different attachments (hook, golf club grip, and motorized claw).*