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Master's Thesis
Academic Year 2022

TsugiGrip: A Wrist-Driven Hand Exoskeleton Grip Assistive Device

Keio University
Graduate School of Media Design

Ka Kit Mok

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Ka Kit Mok

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Abstract of Master's Thesis of Academic Year 2022

TsugiGrip: A Wrist-Driven Hand Exoskeleton Grip Assistive Device

Category: Design

Summary

Weak or limited grip strength and reduced hand motor functions are suffered by many as one ages or suffer from diseases or conditions like spinal cord injury or strokes. Although There are many tools and devices that helps alleviate the inconvenience brought about by the inability to perform daily tasks due to the reduced hand motor function by providing assistive support to the users' hand or help them rehabilitate, most of which are heavy, cumbersome, costly and have to be tethered to either pneumatic actuators or external batteries. These drawbacks limits the accessibility of such devices such that the user cannot use them in daily scenarios, or outside of hospitals and medical treatment centres settings.

TsugiGrip: A wrist-driven hand exoskeleton device rid of the aforementioned shortcomings was designed, fabricated, user-tested and proposed to aid those who suffers from reduced hand motor functions. TsugiGrip does not require any external energy input, motors or actuators. Hence, providing an alternative which user can use use in expanded variety of scenarios.

The physical, psychological as well as social impact of reduced hand motor functions were also explored during preliminary user research in this thesis.

Keywords:

assistive device, exoskeleton, grip strength, elderly, reduced hand motor function, rehabilitation

Keio University Graduate School of Media Design

Ka Kit Mok

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Chapter 1
Introduction

1.1. Background

People from all population and countries suffers from age-associated loss of hand grip strength (will be abbreviated as HGS from here on out), however, the cut off point of what is considered ”weak” grip strength varies amongst different demographic [2]. Research have shown that the weakening of grip strength comes with age, via a muscle deteriorating phenomenon known as ”scarcopenia” [3]. In addition, 50 million people suffer from persistent hand impairments after stroke or spinal cord injury (SCI) around the world [4], causing reduced hand motor functions. Patients with impaired HGS and reduced hand motor function could undergo physiotherapy to regain their hand functions, and sometimes assistive devices are used in conjunction to complement the physiotherapy.

Existing assistive and rehabilitative hand exoskeleton are heavy, cumbersome, costly and have to be tethered to either pneumatic actuators or external batteries. In this project, and a wrist-driven hand exoskeleton rid of the aforementioned shortcomings was designed, fabricated and proposed to aid those who suffers from reduced hand motor functions.

In this thesis, TsugiGrip, a de novo Wrist-Driven Exoskeleton Grip Assistive Device was proposed, designed and tested. The device was designed as an effort to provide a cheap, light, tether-less hand assistive device alternative for people with reduced hand motor functions.

TsugiGrip is an exoskeleton that aid and compliments the hand of someone with reduced hand motor functions. The name TsugiGrip takes inspiration from the Japanese art called Kinstsugi that repairs broken objects with gold. The philosophy that something can be augmented through imperfection rather than be hindered by it.

The needs for the target users were explored via surveys, interviews and user tests. Prototypes were fabricated and tested and hopefully this thesis would inspire other designers to design similar, better assistive devices and make them more accessible for people with reduced hand motor functions.

1.2. The shortcomings of existing devices

Cumbersome and Heavy

Conventional devices are driven by motors or pneumatic actuators that require an air pump. While these types of devices were proven to be effective in aiding the regaining of grip strength, the need for motors and actuators to drive the device makes them too cumbersome and heavy.

Tethered

Existing devices often needed to be tethered to a power source. This means that the user will often have to be seated to use it, or only in a clinical therapy session setting where the user cannot move about performing other tasks. Although there are devices with portable air pumps or battery, having to carry around a heavy air pump or battery is still less than ideal.

No injury protection

Although there are not enough evidence to suggest that this is a major problem, one potential issue with the aforementioned devices is that when these devices exert a continuous force on the user's hand, meaning if it happens that the user feel pain during the contraction of the device, the motion would not be able to respond to the pain and stop since there are no pain feedback loops, hence risking potential injuries.

Cost

Existing assistive/rehabilitative devices cost upwards of hundreds of US dollar, making it less affordable to the masses.

1.3. Objective and Contribution

The objective is to design a hand assistive device that overcome the aforementioned shortcomings. The device that is being proposed in this thesis aims to solve the problem of the fact that hand rehabilitation wearable devices are often too cumbersome to be worn on a day to day basis. The proposed device is driven by the user's wrist movement/flexion as a source of power to drive the grasping motion of the exoskeleton, eliminating the need for any external energy input, in other words, there is no need for tethering. This also means that no motors or actuators or air pumps are required, hence greatly reducing the weight of the device and its portability. The device being wrist-driven also mean that the exerted force on the back of the hand is controlled by the user, should the user experience any pain while using the device, the user can adjust the force being exerted on the hand by adjusting their wrist movement. The proposed device would be entirely mechanical and free of the need for motors or actuators, a 3D-printable device that would be cheap to manufacture and widely accessible to the masses.

Wrist-driven hand assistive devices are currently non-existent. such wrist-driven or similar devices only exist in the realm of prosthetic for amputees. The proposed device will be the first of its kind.

Chapter 2
Related Works

2.1. Current assistive devices and methodology

Conventional assistive or rehabilitation device that help regain HGS usually take the form of a glove or exoskeleton, they work by asserting force on the back of the fingers to provide assistance for finger flexion and extension. Some assistive devices provide active support to help the user in completing tasks with the hand while some take the rehabilitation approach where regaining HGS by training and exercising is the key methodology.

2.1.1 Actuator-driven Exoskeleton

Actuator-driven Exoskeleton simply assist the grasping action of the user by exerting force on the user's fingers, the grasping motion is triggered by the user's direct input of the device.

Example: Syrebo Rehabilitation Glove

The Syrebo Rehabilitation Glove is a pneumatic actuator powered exoskeleton device that help the user by providing griping assistance and rehabilitation support. It needs to be tethered to a battery and air pump in order for it to function.

Figure 2.1 Syrebo Rehabilitation Glove: Actuator-driven Exoskeleton — Source: https://bit.ly/3PZ1k3U

2.1.2 EMG-driven Actuated Exoskeleton

EMG (eletromyogram)-driven actuated exoskeleton (Figure 2.2) take the eletromyographic signal from the user's muscles by attaching a EMG electrode (signal receptor) on the arm and translate it into a grasping motion in the exoskeleton by actuating the linear actuators which generate the finger flexion/extension [5]. This kind of assistive device not only help with flexion and extension of the user's fingers, but also helps rebuild the neurological pathways/connections between the brain and the muscles in the hand.

Example: Hand of Hope

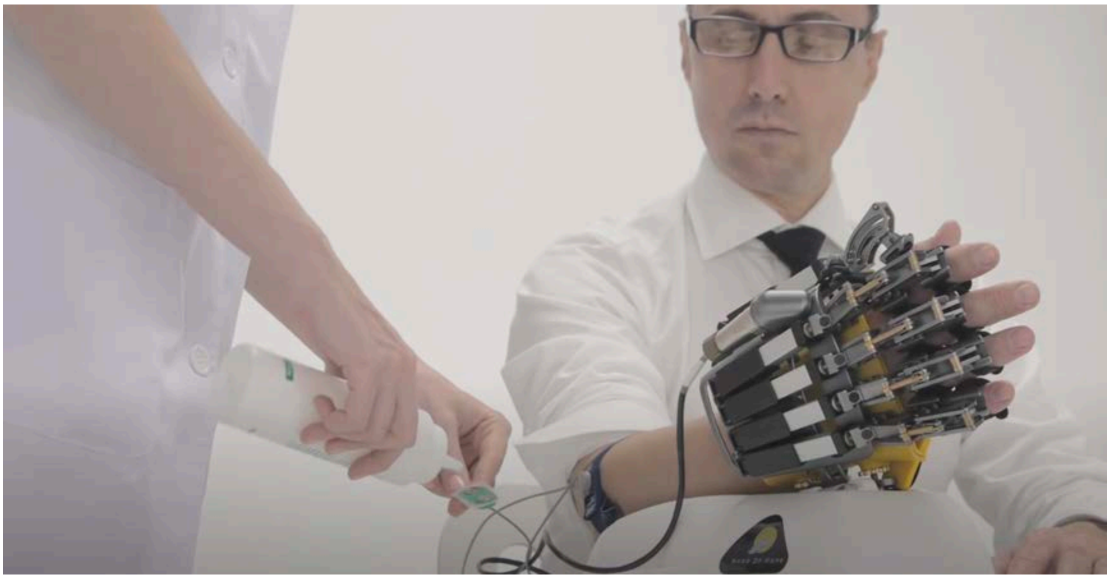

Figure 2.2 Hand of Hope: EMG-driven Exoskeleton — Source: YouTube Video - https://bit.ly/3oP0Rp5

2.1.3 Resistance training orientated exoskeleton

Resistance training oriented exoskeleton provides a platform to which the user can regain their HGS through resistance exercises. This type of passive assistive device does not provide active support, but rather rely on the user to actively exercises their hands in order for them rebuild the muscles strength as well as the neuro-connection between the brain and the msucles in the hand.

Figure 2.3 Saebo Resistance Training Glove — Source: https://bit.ly/3d4ODpN

Chapter 3
Design Process

3.1. Fieldwork Research

3.1.1 Survey

To obtain a better understanding of the struggle that comes with age, especially to better understand how the lack of HGS affects the daily activities of the elderly, a contact with an elderly home in Tokyo was established (Figure 3.1). The goal was to be able to interview residences of the elderly home who are in need for active assistance on a daily basis, and gain insights about their daily struggles and needs for assistance, as well as any insights as to their state of mind when being on the receiving end of the assistance. After numerous email exchanges and Zoom calls with the director of the elderly home to communicate the goal of my search, it was concluded that the residents at said elderly home might not be the best place for the survey as the residents there require minimal daily assistance. I was then introduced to four other day care centres where residents requires at least level 1 assistance(explain level 1 assistance). Through a personal contact, a contact with elderly care centre in Kyoto was also established.

However, due to the circumstances under the COVID-19 pandemic, face to face interviews has become unfeasible and written surveys and online interviews were put in motion instead.

Figure 3.1 Zoom meeting with Kobayashi San from the Meugro-ku Elderly Centre

Survey Design

The target of the surveys are ideally over the age 70 who requires daily assistance. And since the goal of the survey was not to obtain quantifiable statistical data but rather to gain insights about the individual's struggle, no personal information were collected.

Since the subjects are elderly, the goal was to design a survey that is easy to read, understand and respond to. Prof. Giulia Barbareschi was consulted for the design of the survey because of her rich experience in doing elderly and disability related research. The survey was first written in English and then translated into Japanese. The survey were then checked and validated question question with the help of a fellow researcher who works at the aforementioned elderly centre to make sure the translation and language, as well as the font size were all optimized for the elderly individuals receiving the survey.

Survey Results

27 surveys were sent to 5 different day care centres and 27 surveys were retrieved.

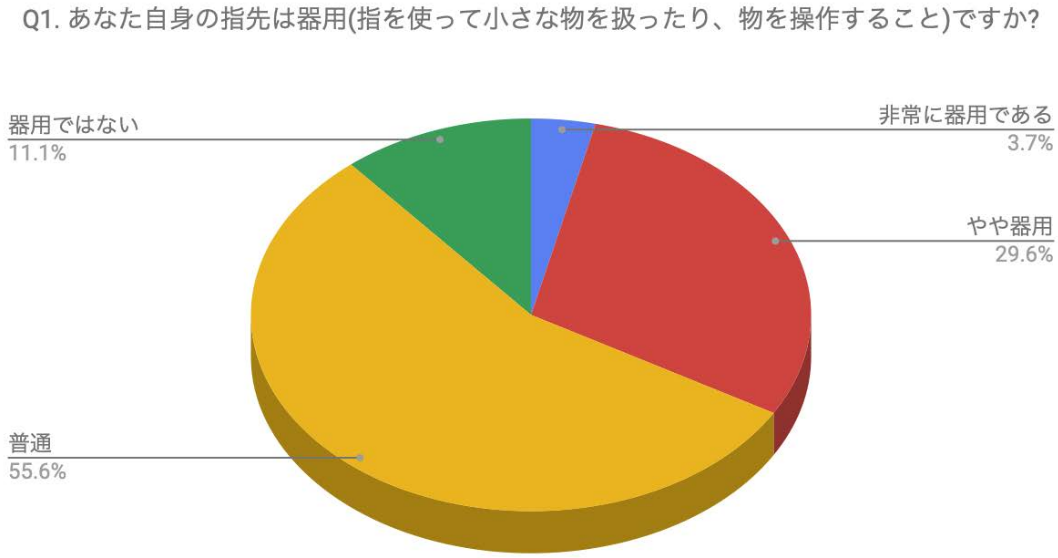

Figure 3.2 Q1. How would you describe your confidence level when it comes to doing things with your hands?
Blue: Very Confident
Red: Moderately confident
Yellow: Somewhat Confident
Green: Not confident at all

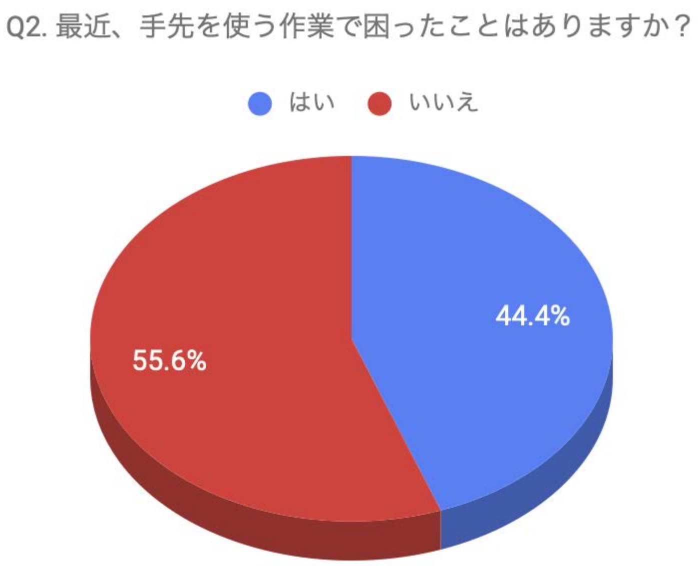

Figure 3.3 Q2. Recently, have you experienced any difficulties when performing tasks with your hands?
Red: No
Blue: Yes

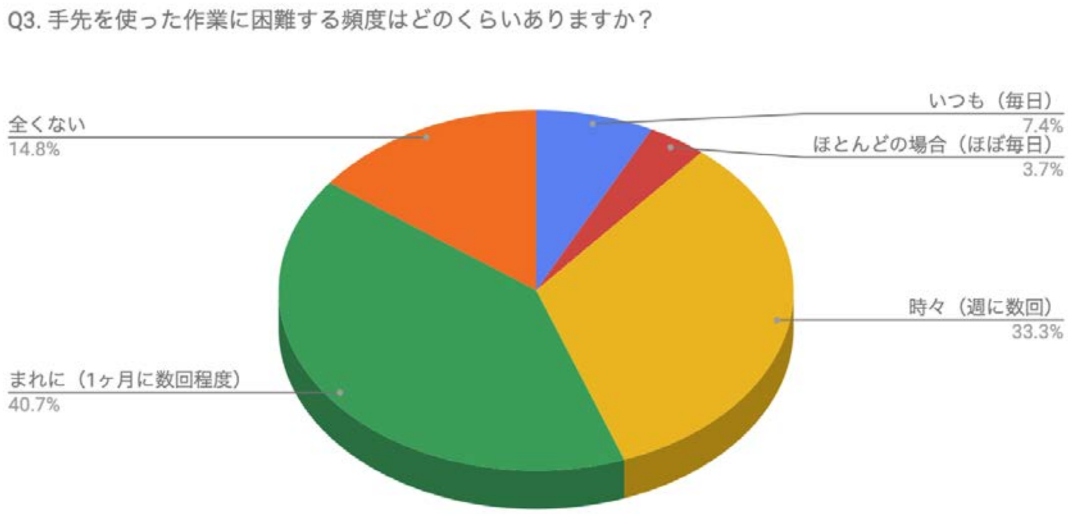

Figure 3.4 Q3. How frequently do you find difficulties in performing tasks with your hands?
Blue: All the time (Everyday)
Red: Most of the time (Almost everyday)
Yellow: Sometimes (Several times a day)
Green: Rarely (A few times in a month)
Orange: Never

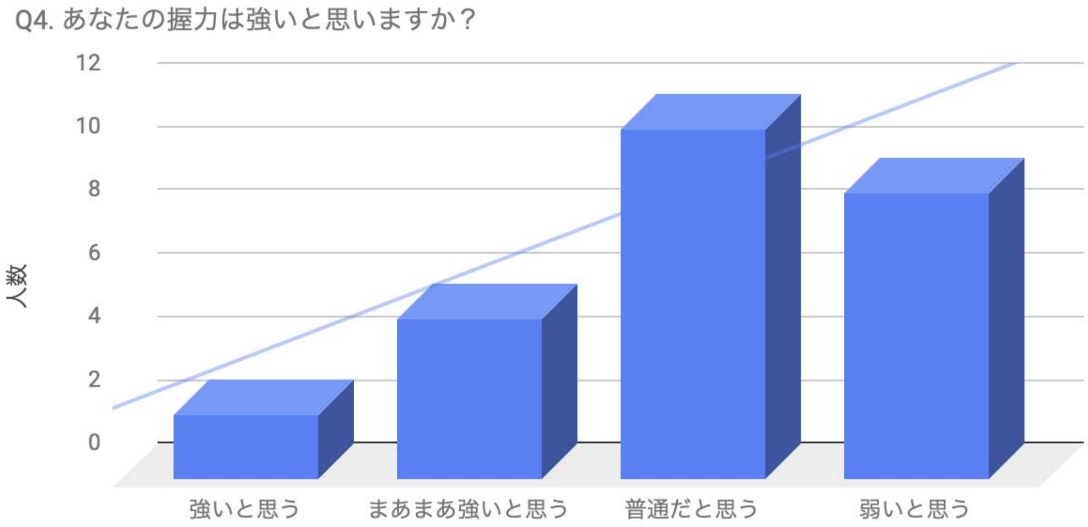

Figure 3.5 Q4. How would you rate your grip strength?
X axis: no. of people
Y axis: Strong; Fairly strong; Normal; Weak

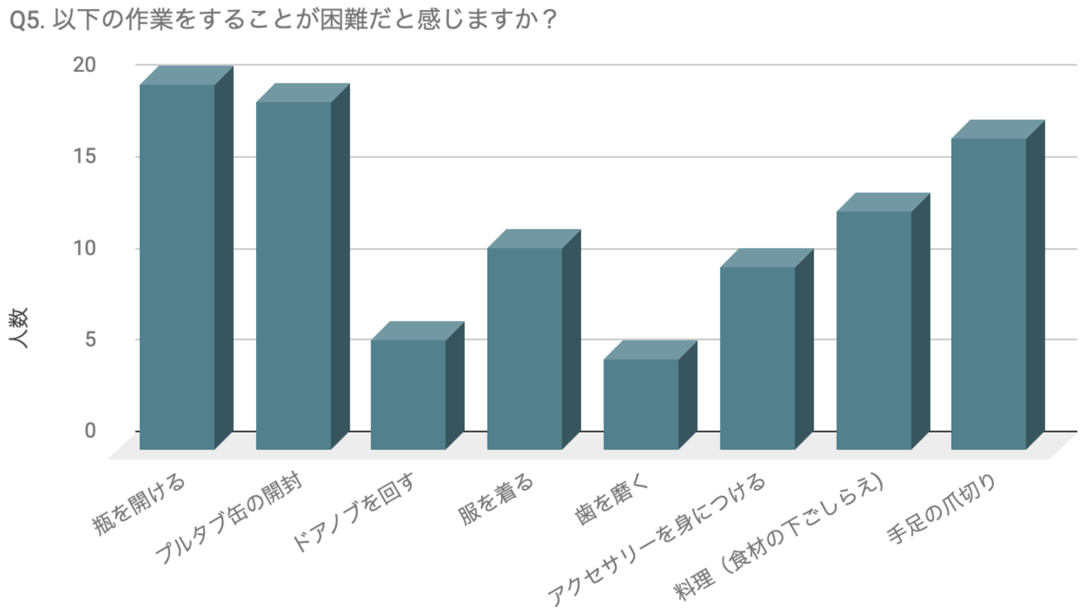

Figure 3.6 Q5. Do you find doing the following tasks difficult?
X axis: no. of people
Y axis: Opening Jars and bottles
Opening pull-tab cans
Turning door nobs
Putting on clothes
Brushing your teeth
Putting on jewelry
Cooking(Preparing ingredients)
Clipping finger/toe nails

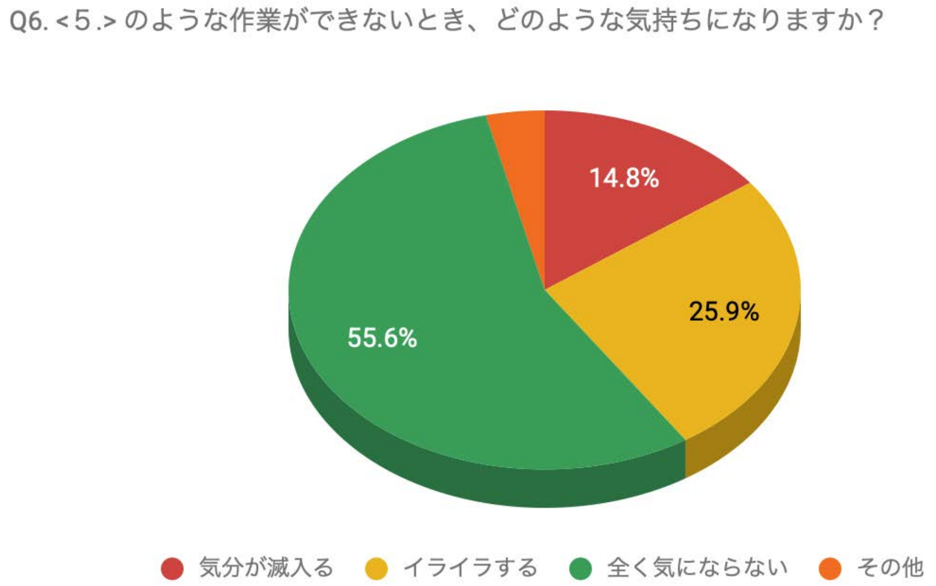

Figure 3.7 Q6. How do you feel whhen you cannot perform the tasks in Q5?
Red: It ruin my moods
Yellow: It frustrates me
Green: It does not bother me at all
Orange: Others

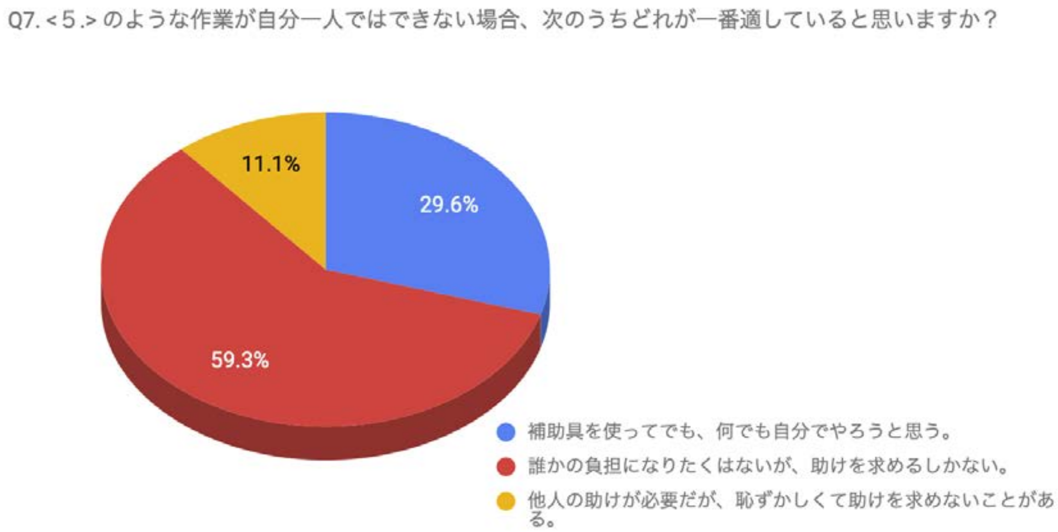

Figure 3.8 Q7. In the circumstances where you cannot perform the task on your own, which statements suits you the most?
Blue: I would try to do everything myself even if it requires using tools to help me.
Red: I don ’ t want to become a burden on someone else but I have no other options but to ask for help.
Yellow: I needed help from others but I sometimes feel too ashamed to ask for help so I don ’ t.

Figure 3.9 Examples of assistive tools presented

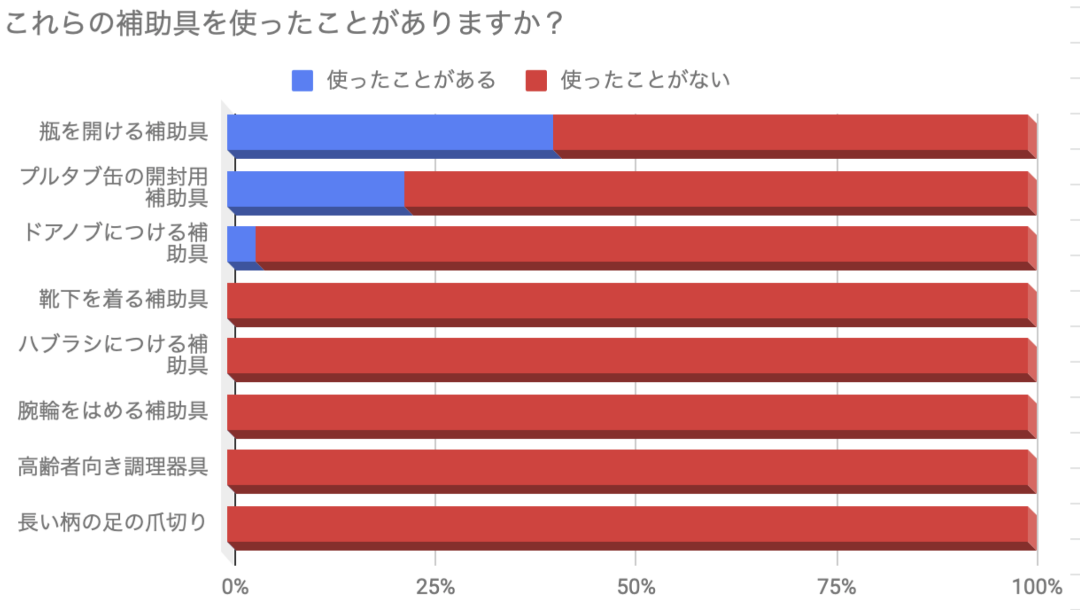

Figure 3.10 Have you used any of the following assistive tools before?
X axis: Bottle/lid opener
Pull-tab opener
Door nob adapter
Tools for putting on socks
Toothbrush assistive handle
Tools for putting on jewelry
Special knife for elderly
Nail clip extender
Y axis: percentage of participants
Blue: Yes I have
Red: I have not

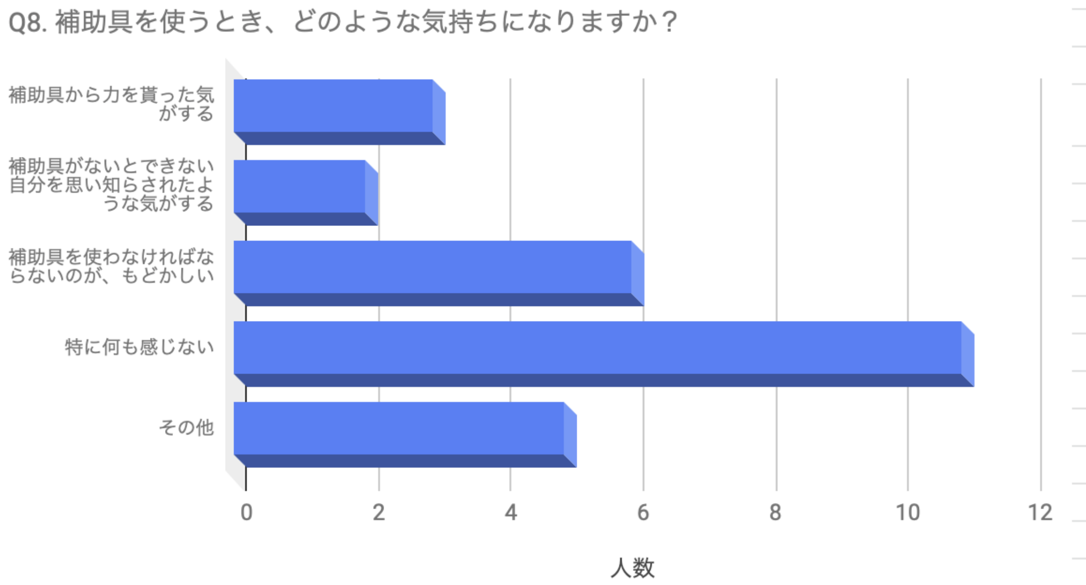

Figure 3.11 Q8. When using assistive tools, how does it make you feel?
X axis: I feel empowered by the tools
I feel like I am being reminded of my inability to do things without tools
I feel frustrated that I have to use tools
I don't feel anything in particular
Others
Y axis: Number of participant

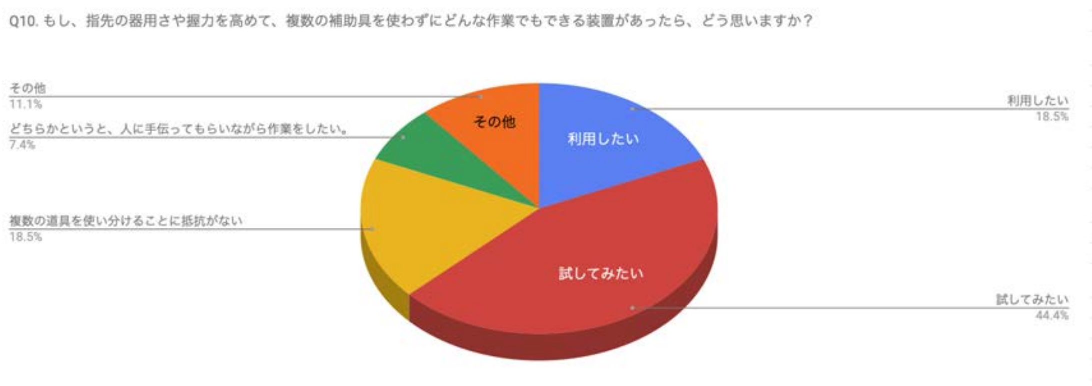

Figure 3.12 Q10. How would you feel if there is a device that can enhance your finger dexterities and grip strength so that you can perform any tasks without using multiple tools?
Blue: I would be very happy to use it.
Red: I would be very happy to try it
Yellow: I am fine using multiple tools for different tasks
Green: I would rather ask people to help me with doing those tasks.
Orange: Others

3.1.2 Survey Results Evaluation

In the survey, potential user targets were asked questions about their HGS and what they struggled with the most when using their hands to complete different daily tasks. A number of assistive tools were also presented in the survey and were asked whether the survey participant has used the examples before (Figure 3.9). Figure 3.10 show the results.

The results shows that only 11.1% of the surveyee feel that they are confident with doing tasks with their hands. The majority (55.6%) feel that they are somewhat confident (Figure 3.2). Only 44% have experienced difficulties with doing tasks with their hands recently (Figure 3.3. Most surveyee did not experience difficulties in using their hands to do things frequently with the majority (40.7%) experiencing difficulties only a few times in a month (Figure 3.4). When asked to rate their HGS, the majority think their HGS is weak or normal, few think they have high HGS (Figure 3.5). When asked what tasks the struggle with the most in regards to using their hands, most surveyee find opening bottles and pull-tab cans as well as cutting finger/toe nails the most difficult (Figure 3.6). It is also very important the mental state of the surveyee when they struggle with doing tasks with their hands, surprisingly, the majority (55.6%) are not bother by the fact that they could not perform certain tasks. However, 14.8% and 25.9% of the surveyee feel that not being able to doing tasks with their hands ruins their moods and frustrates them respectively (Figure 3.7). When ask whether they will ask for assistance or try to mange on their own when doing difficult tasks, 59.3% of them feel that they do not what to be a burden for other people but have no choice but to ask for help and 29.6% would try to complete tasks to the best of their abilities with the help of assistive tools (Figure 3.8).

Perhaps the most surprising result is the high number of surveyee who have no used any of the assistive devices presented to them (Figure 3.10). This result is interesting as there could be a lack of awareness about existing assistive devices that are available to the target users.

It was also interesting to learn about the mental influence of using assistive devices. When the surveyee were asked whether using an assistive device makes them empowered or be reminded of their inability, the majority actually do not feel anything in particular. It could be due to the fact that the majority of the surveyee in the survey have never used assistive devices before.

When asked whether or not they will try to use a multipurpose hand assistive tool, the majority (18.5% + 44.4%) said they would like to try and use it (Figure 3.12).

3.1.3 Remote Interviews

9 individuals were interviewed for this preliminary research to gain more insights about the needs of the potential targets. Video interviews were carried out to hopefully obtain more in-depth information that conventional written surveys could not provide. 6 of whom fall into the same group as the people who have taken the survey with the oldest at 90 years old. The remaining 3 works in related industries where one used to work as a caretaker at a elderly home in Canada, one work as a recreation therapist at a elderly care centre in Canada and the last

currently work as physiotherapist in Hong Kong.

3.1.4 Important insights from remote interviews

These individuals were interviewed remotely due to geographical restrictions. Below are some key takeaways from these interviews.

1. Besides the lack of grip strength, finger dexterity plays an equal, if not more important role in doing daily tasks with the hand.
2. Besides grip strength and dexterity, the sense of touch also play a very important role in performing tasks with the hand.
3. No research could tell you the embarrassment one experiences when they need to ask someone else to wash their body for them, or things as little as asking someone to clip their toe nails for them.
4. Even when an assistive to is presented, one might need to warm their hands up (exercise the hand) before using the tool.
5. Thumb and palm strength is relied on when the rest of the fingers do not have enough strength.
6. Some with hand impairment not only lack strength, but experiences muscle pain.
7. Instead of a consistent lack of grip strength, one might lose grip strength and drop things all of a sudden.
8. One may not use assistive tools due to one's ego.
9. The reduction in hand motor function cause the lack of ability to participate in social and group activities such as recreational therapies that involves drawing if one cannot even hold a pen.

Figure 3.13 interviewee 1

Figure 3.14 interviewee 2

Figure 3.15 interviewee 3

Figure 3.16 interviewee 4

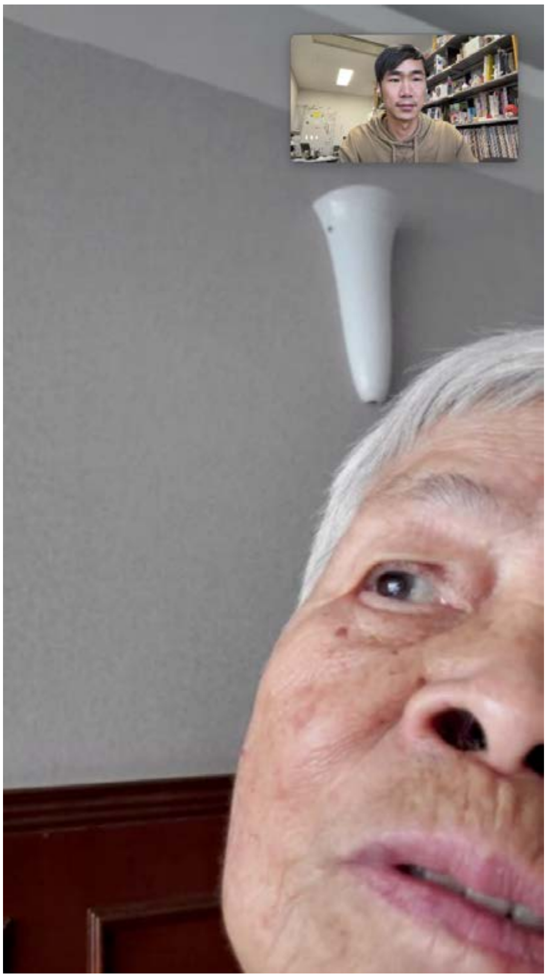

Figure 3.17 interviewee 5

Figure 3.18 interviewee 6

Figure 3.19 interviewee 7

Figure 3.20 interviewee 8

3.1.5 Conclusion

Despite the limitation in sample size, a lot of unexpected and useful insights were gathered with the survey and remote video interviews. These information would be immensely useful for any future studies or tools development regarding individuals with reduced hand motor functions.

More will be discussed in the conclusion at the end of the thesis.

3.2. Ideation

3.2.1 Sympathetic Device

To better understand the need of individuals with lack of HGS or hand impairment, a sympethic hand device was created with a lego-like toy called K'nex. The device takes the form of an exoskeleton that attached to the back of the hand (Figure 3.21) with rubber bands strapped to the fingers. The goal is to limit the movement of the fingers of the hand and go about doing daily tasks so as to experience the difficulties and hurdles faced by people with hand impairment in order to design an assistive tool that better meet their needs.

3.2.2 The Experiment and findings

The device was wore for a day and it was not taken off even once during the experiment. Daily tasks such as going to the toilet, washing hands, opening bottles, etc, was found to be extremely inconvenient. Opening bottle (Figure 3.22) was extremely difficult with the restricted hand mobility. Holding utensils like chopsticks or forks and knifes was borderline impossible. The aforementioned is also too for holding any small, thin objects that requires fingers to wrap around to hold such as a toothbrush. Another unexpected finding is how difficult it is to reach into to pocket to take a wallet out due to the size of the device and restricted finger dexterity. Wearing the device for a prolonged period of time was also painful as the rubber bands used exerted a lot of pressure on the fingers.

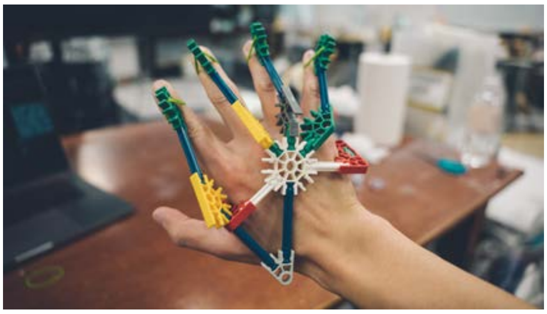

Figure 3.21 A sympethatic exoskeleton made with K'nex

Figure 3.22 Opening a water bottle while wearing the sympathetic device

3.2.3 Contribution of the experiment

After wearing the sympathetic device, it was apparent that if a hand assistive exoskeleton is to be designed, and such device is to be wore for a prolonged period of time on a daily basis, the device has to be thin and light enough so that it would not get in the way of performing tasks that requires fingers dexterity, a device that is not too cumbersome so that it would hinder tasks such as getting things out of the pocket. The device would also need to be water-proof so that the user can still wash their hands while wearing the device.

A second iteration of the sympathetic device was proposed with an improvement where the level of finger movement restriction could be adjusted with a spring. Figure 3.23 shows the proposed device being worn.

Although the idea of a restrictive sympathetic device was not the goal of the proposed assistive device in this thesis, creating the device gave great insights as to how an exoskeleton should be designed.

Figure 3.23 A sympathetic device with adjustable tension being worn

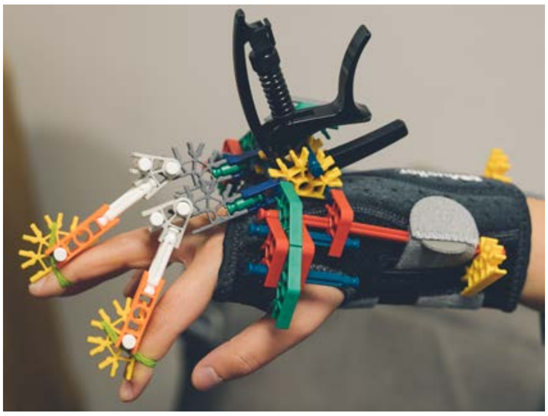

Figure 3.24 A sympathetic device with adjustable tension

3.2.4 Sketches

Figure 3.25 shows the early design of an exoskeleton for the index finger. The exoskeleton sits on the back of the index finger while part of the exoskeleton wraps around the palm and wrist. Figure 3.26 shows how the proposed mechanism works where with the twist of the wrist, the bending of the index finger exoskeleton would be triggered, hence providing support of finger flexion. The proposed exoskeleton in Figure 3.25 and Figure 3.26 is inspired by KinetiX, a multi four-bar linkage system that utilises auxetic materials and their compliant properties to create structures that can bend and transform when triggered by a an input force (compression) [6].

Figure 3.27 shows another sketch of the mechanism design. Figure 3.28 shows early drawings of the alternative attachment of the exoskeleton device. Figure 3.29 shows a sketch of a hand to better understand the anatomy of the hand. Figure 3.30 shows a sketch of a hand with attachment points of the exoskeleton.

Figure 3.25 Early sketch of an exoskeleton device: the red sketch shows how the device attaches to the user's hand

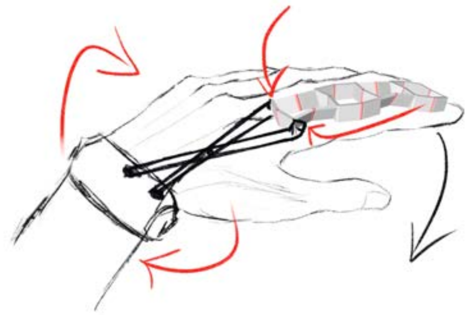

Figure 3.26 Early sketch of the early mechanical design of the wrist-driven exoskeleton device

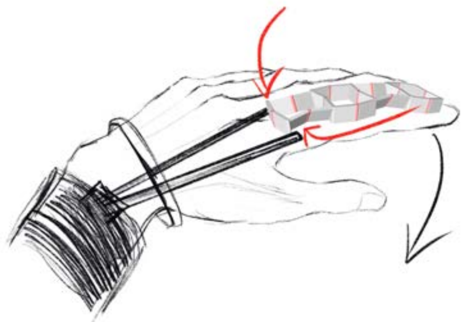

Figure 3.27 Early sketch of the early mechanical design of the wrist-driven exoskeleton device 2

Figure 3.28 Sketch of the early design of the finger attachment of the exoskeleton device

Figure 3.29 caption

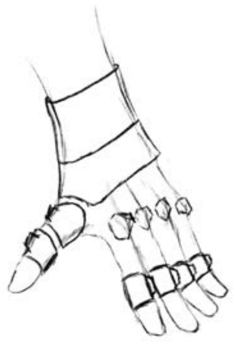

Figure 3.30 Caption

3.3. 1st Prototype

3.3.1 Mechanism Test

One of the linkage-based transformation design structures illustrated in the KinetiX paper was used as a model for the exoskeleton. The multi-block structure consist of four compliant four-bar linkage building blocks that are interconnected and bend as a whole when one of the blocks is compressed [6]. Figure 3.31 shows a single four-bar linkage block made of K'nex. Figure 3.32 shows the complete structure composed of four four-bar linkage blocks made out of K'nex.

The mechanism was created to test if the proposed mechanism works, i.e. by compressing the first block of the structure, the rest of the structure will bend.

The structure worked as intended as one block was compressed the entire structure deformed and bend.

Figure 3.31 A four-bar linkage block made with K'nex

Figure 3.32 A structure with four four-bar linkage block joined together

3.3.2 Paper Prototype

A paper prototype of the four-bar linkage structure was made to find the suitable size of the device that would fit the back of the finger (Figure 3.33. The prototype was put on the back of the index finger to measure the suitable size of the exoskeleton (Figure 3.34). Due to the material properties of paper, the mechanism of the structure could not be tested.

Figure 3.33 A paper prototype of the four-bar linkage structure

Figure 3.34 The paper prototype sitting on the back of the index finger for size fitting of the exoskeleton

3.3.3 Material and Design Testing

A compliant four-bar linkage block was drawn with Shapr3D, a 3D CAD software (Figure 3.35). The block has no mechanical hinges but only special cutouts at the compliant hinges. The part was then subjected to 3D printing with ABS material as shown in Figure 3.36.

Figure 3.37 shows the printed four-bar linkage block. However, due to the lack of malleability of the material being used, the block disintegrated when compression is applied.

Instead of relying on the malleability of the material the allow for deformation of the block, i.e. making a monolithic block, the compliant hinges were replaced with cello tapes instead. The final structure is show in Figure 3.40 where when compression is applied on the first block, the rest of the structure deformed and bend as designed.

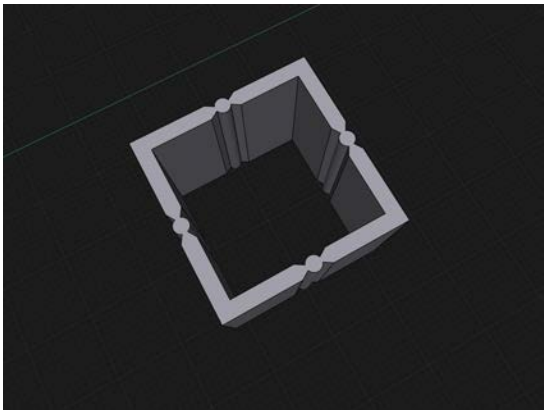

Figure 3.35 3D drawing of a compliant four-bar linkage block

Figure 3.36 A compliant four-bar linkage block being printed

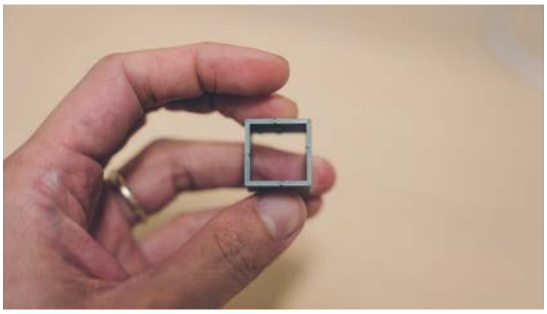

Figure 3.37 A 3D printed block prototype

Figure 3.38 The block was broken when compression is applied due to the lack of malleability of the material

Figure 3.39 Top: K'nex prototype; Middle: Paper prototype; 3D printed prototype

Figure 3.40 The 3D printed structure deformed and bend when compression is applied on the first block

3.4. Evaluation

The printed compliant exoskeleton structure fitted the back of the index finger (Figure 3.41) and the mechanism did indeed worked. However, the degree to which the structure can deform is not enough to make a finger fully bent. Figure 3.42 shows the structure in its fully deformed state, but it was still much less than the angle which the finger could bend. In addition, the material and mechanical stiffness of the structure is also too weak to provide mechanical support to the finger. Hence the decision of not using this mechanism of the design of the exoskeleton was concluded.

Figure 3.41 The compliant exoskeleton resting on the index finger

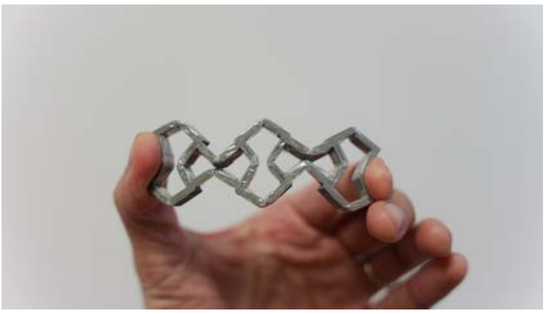

Figure 3.42 The structure under complete deformation

3.5. Second Prototype

3.5.1 Evaluation

A second attempt was made to design a wrist-driven exoskeleton design with K'nex. However, due to the limited choice of different lengths, size and shape of the K'nex parts, although the wrist movement did transform into a mechanical movement of the exoskeleton finger, the movement was very limited and could not cover the full range of movement of the finger. Ideally the mechanism should be able to move in relation to the metacarpophalangeal (MCP), distal in- terphalangeal (DIP), and proximal interphalangeal (PIP) joints (Figure 3.45) [7]. Another way other than using toy models like K'nex to design the mechanism must be used.

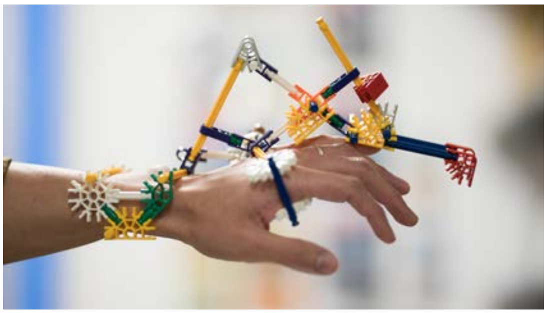

Figure 3.43 A wrist-driven exoskeleton design being worn

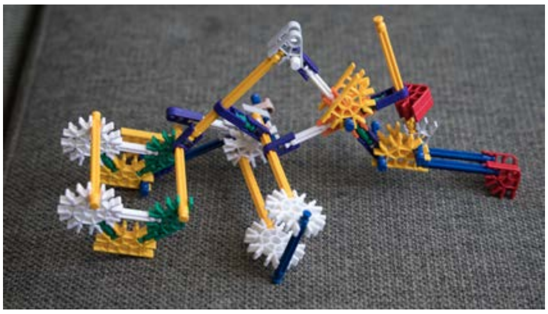

Figure 3.44 A wrist-driven mechanical design

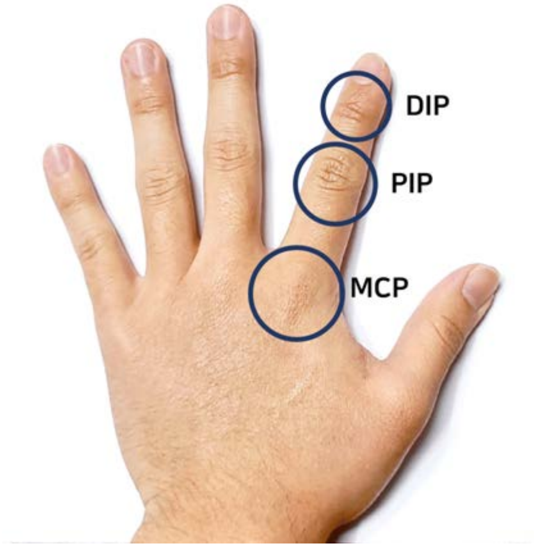

Figure 3.45 Hand anatomy — Source: [1]

3.6. Third Prototype

Base on the results from the previous prototypes, a mechanism that better accommodate the full range finger movement was created. The goal of this prototype was to approximate and mimic the full range movement of a finger for the exoskeleton device. A 3D CAD prototype was drawn using Fusion 360, a CAD software. The degree of movement of the proposed mechanism was tested within the CAD software by using virtual joints (Figure 3.46). The prototype was then printed in SLA (Figure 3.47) and assembled (Figure 3.48).

The movement of the mechanism was able to mimic that of a finger, but connecting point was needed to drive the mechanism. A K'nex type clip was incorporated into the driving end of the mechanism to fit a K'nex rod which would act as a force transmission bridge between the finger mechanism and the drive input (Figure 3.49). However, the PLA material was not flexible enough to endure the deformation when the rod is put in (Figure 3.50. A K'nex piece was incorporated into the design with the assumption that the K'nex structure would allow more deformation leeway (Figure 3.51). A second prototype using SLA (Stereolithography) printing technology instead of FDM (Fused Deposition Modeling) was also created to see if the former printing method would yield a more rigid connection point with the rod (Figure 3.52). A palm holster (Figure 3.53) was also printed to attach the assembly to the hand.

3.6.1 Evaluation

The mechanism was able to simulate the movement of the finger, however, this mechanism acts more like a prosthetic finger rather than an exoskeleton. The SLA printed prototype did yielded a more rigid connection point for the driving rod, however, the finger mechanism was too rigid to be driven by the displacement of the driving rod. Upon displacement of the driving rod, too much strain was exerted on the K'nex connection point and it deformed, resulting in a incomplete transmission of energy from the input to the finger mechanism. Nevertheless, the mechanism served as a good starting point for designing the next finger exoskeleton design.

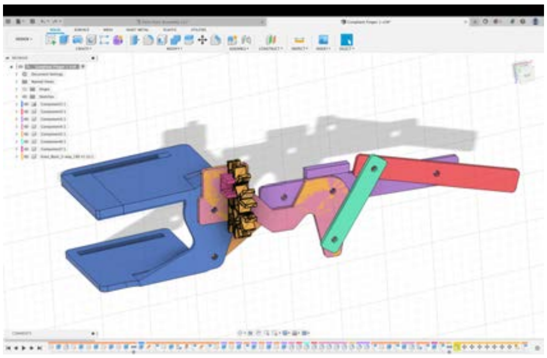

Figure 3.46 3D CAD drawing of the new finger mechanism

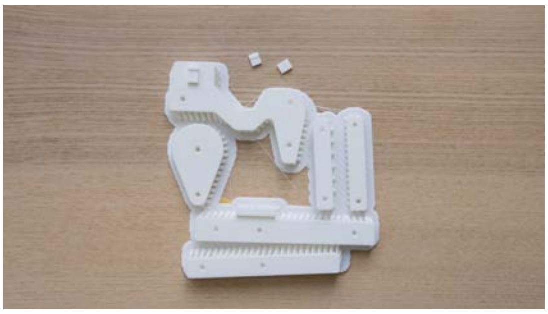

Figure 3.47 Caption

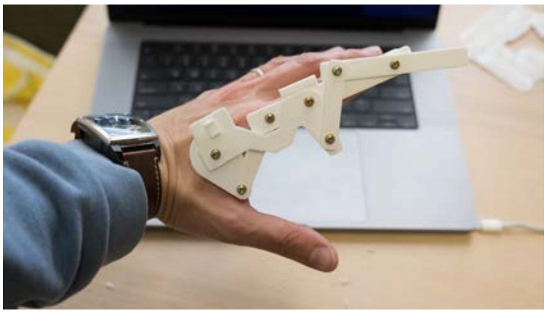

Figure 3.48 New finger mechanism printed and assembled

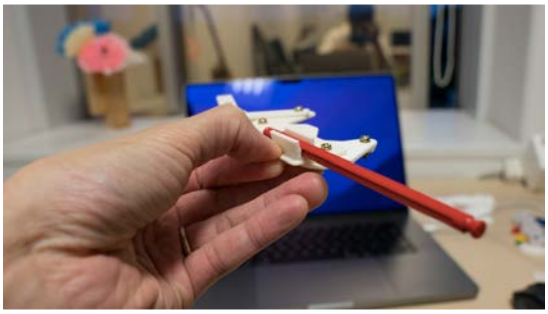

Figure 3.49 Caption

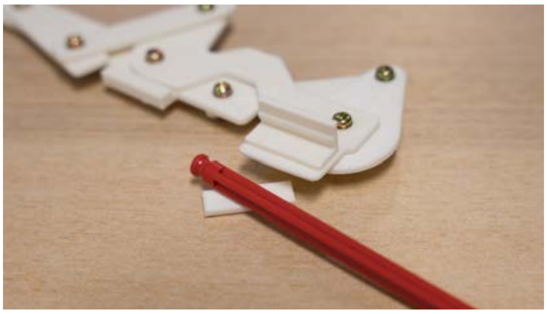

Figure 3.50 A broken K'nex joint

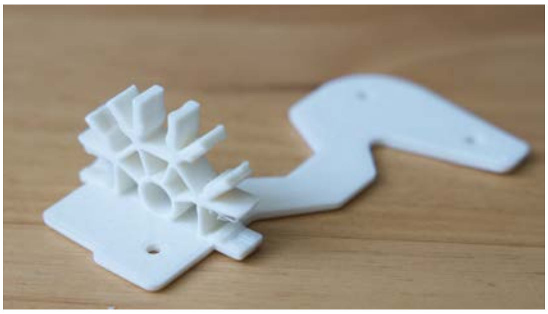

Figure 3.51 A new K'nex joint

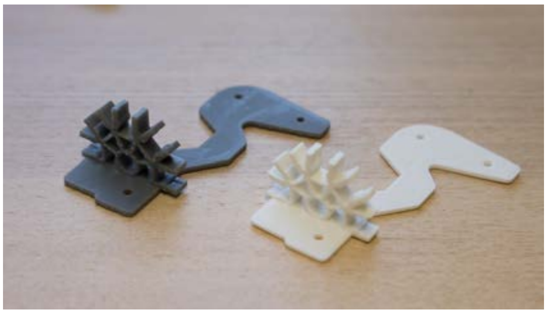

Figure 3.52 Left: SLA Printed Prototype Right: FDM Printed Prototype

Figure 3.53 The palm holster

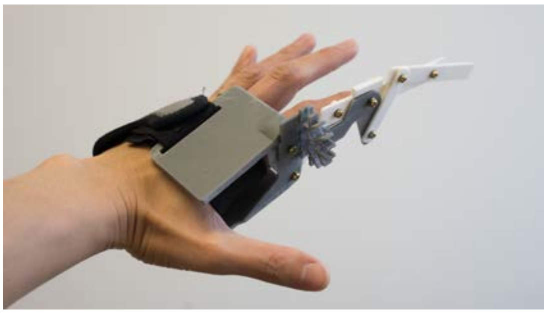

Figure 3.54 The 3rd prototype assembly being worn

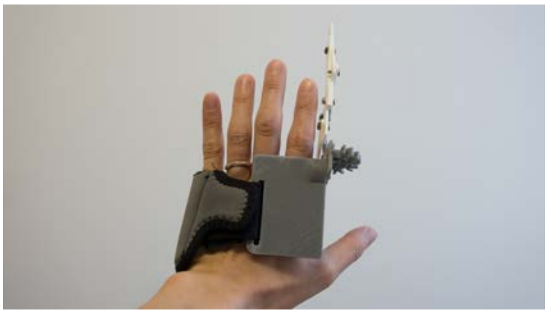

Figure 3.55 Top view of the 3rd prototype

3.7. Fourth Prototype

Following the 3rd prototype, a 4th prototype was designed with a focus on the wrist mechanism that translate the displacement in the wrist to the grasping movement of the exoskeleton fingers (Figure 3.65). A mechanism was designed so that part of the mechanism would wrap around the the forearm and the other half would be attached to the palm of the hand (Figure 3.66). Connecting the two components is a mechanical mechanism that register the displacement of the wrist and translate the displacement into a grasping motion of the mechanical finger exoskeleton (Figure 3.64, 3.71).

3.7.1 Mechanism Testing

The proposed wrist mechanism (Figure 3.58, 3.59, 3.60) was printed with the SLA method to achieve higher stiffness and rigidity as well as precision since the working of the mechanism relies on the precise placement of the components involved and the mechanism needed to be able to withstand the load between the wrist and the exoskeleton fingers components. The design was then worn and tested (Figure 3.61).

The wrist mechanism worked as intended and matches the simulated motion in the CAD software.

3.7.2 Combining the wrist-driven mechanism with exoskeleton fingers

A four-bar linkage based finger structure (Figure 3.70) was developed in CAD and was added to the working wrist mechanism with slight adjustments (Figure 3.62, 3.63, 3.64). The entire exoskeleton device works so that when the wrist is bend upward with the palm facing up the exoskeleton fingers would push towards the user's fingers and provide support to the grasping action (Figure 3.67).

3.7.3 Testing and evaluation

Mechanical errors

The entire prototype was 3D printed and worn and the effectiveness of the device was evaluated. While in the simulation of the mechanism within the CAD software was able to use the wrist mechanism to drive the bending of mechanical fingers at the MCP, PIP and DIP joints, the 3D printed version were only able to drive the MCP joints. This was a result of the difference between the material properties inside the CAD software and in the reality. In the CAD software all the components fit together rigidly with no mechanical gaps and deformation. But in reality when the prototypes is being put together with bolts, nuts and screws, there often are a lot of mechanical errors, gaps and deformation.

Fitting

The size of the device was a rough estimate of an average hand and therefore did not fit the contour of the hand. The fitting of a device that aims to be an assistive device not only affect the comfort of the user when wearing the device, how snugly the fit is also affect how the device function. In the user test that was done both the palm end and the forearm end of the device was too loosely fit, causing the exoskeleton fingers to not fall on the back of the fingers thus not able to provide support.

Four-bar linkage Exoskeleton

It was clear that use a four-bar linkage finger mechanism is not ideal as an exoskeleton. The mechanism do not contain any cavities for the user's finger to sit in, thus failing to attach to the user's finger and act as an exoskeleton. The mechanism also did not account for the extension in length when the fingers is in a closed position, the mechanism needs to able to extend as the fingers closes.

Thumb

The prototype also did not account for the thumb. The thumb is an integral part of any gripping motion and shall not be omitted. In this prototype however, since the wrist-mechanism is located on the pinky side of the hand, it was mechanically unfeasible to also support the thumb from the opposite side. If the wrist mechanism is put in the thumb side of the hand, the thumb would get in the way of the mechanism.

Conclusion

The next prototype needs to have a better fit to the hand, one that fits the user's hand without causing any discomfort and allow for the mechanism to optimise it's motion. The finger exoskeleton also need to allow the individual movement of the MCP, PIP as well as the DIP joints. A cavity is required for each finger to snugly fit into the exoskeleton to allow for maximum contact between the device and the hand. In additional, the exoskeleton would need to be able to extend, or at least cover the entirety of the back of the finger as the each finger reach its closed/grasped position. A support mechanism for the thumb would also need to be developed.

3.7.4 Evaluation by a physiotherapist

The proposed design were subjected to a review by a physiotherapist via a remote interview (Figure 3.56). The CAD design and methodology of the device were shared with the physiotherapist to gather feedback and insights. The followings are some key takeaways:

1. The device is designed using the wrist as a driver in mind, however, although it is not always the case, normal grip strength and wrist strength are usually inseparable. That is, if an individual has poor grip strength, he/she might also have weak wrist strength.

2. The design of the 4th prototype is such that the exoskeleton reach a closed position when the hand rotates forward, away from the posterior side of the forearm. However, according to the physiotherapist, during a griping motion the wrist is actually at a extended position where the hand moves backwards, rotating towards the posterior side of the forearm(Figure 3.57).

3. According to the physiotherapist, the merits of the proposed devices are:
   - Less costly and more affordable (machine/ robotics are costly).
   - No need to take therapies in a clinical, seated setting.
   - Hygiene - if the device is made out of only 3D printed materials or plastics it would be much easier to clean.

The feedback from the interview with the physiotherapist will be taken in to account in all future iterations.

Figure 3.56 Interview evaluation with a physiotherapist

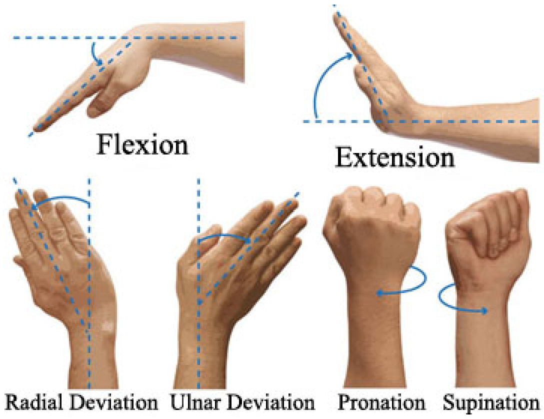

Figure 3.57 Flexion and extension of the wrist — Source: https://bit.ly/3OZ3pvt

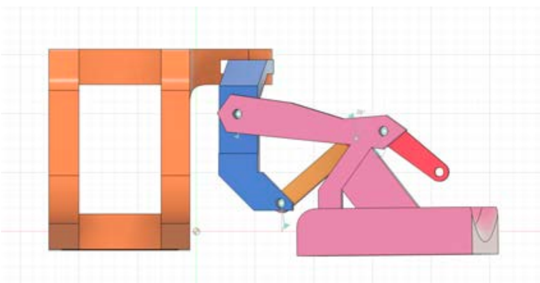

Figure 3.58 CAD drawing of wrist mechanism angle 1

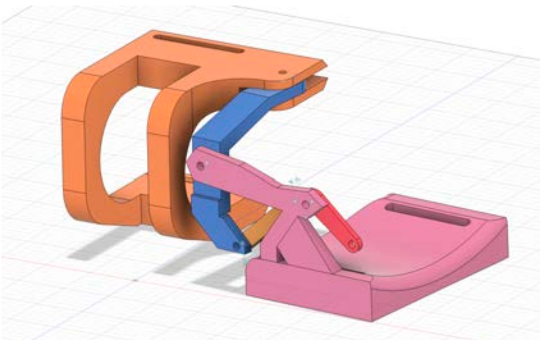

Figure 3.59 CAD drawing of wrist mechanism angle 2

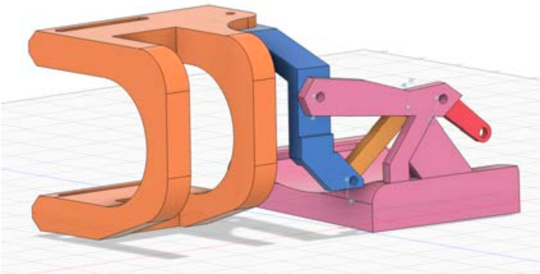

Figure 3.60 CAD drawing of wrist mechanism angle 3

Figure 3.61 Wrist mechanism printed and tested

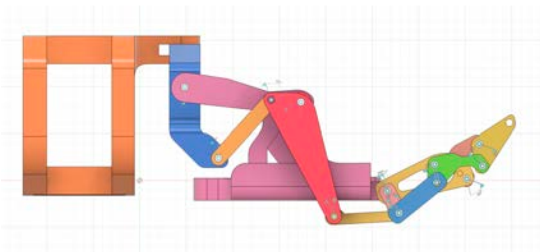

Figure 3.62 CAD drawing of 4th prototype angle 1

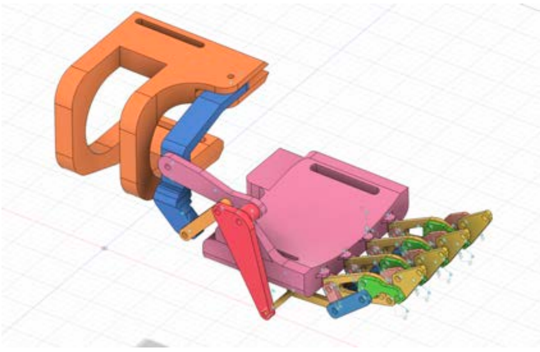

Figure 3.63 CAD drawing of 4th prototype angle 2

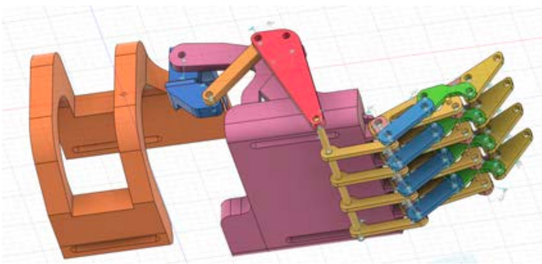

Figure 3.64 CAD drawing of 4th prototype angle 3

Figure 3.65 4th Prototype

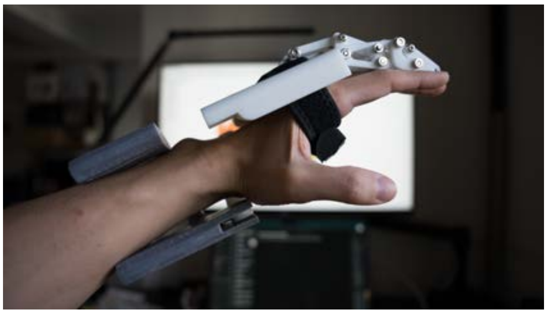

Figure 3.66 4th prototype being worn 1

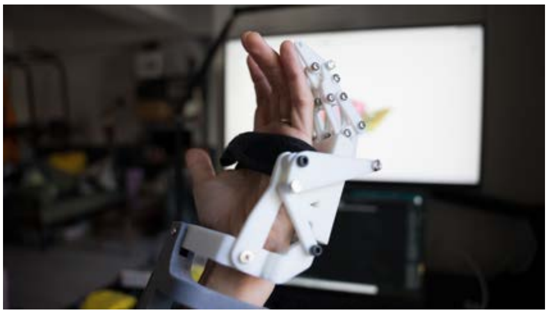

Figure 3.67 4th prototype being worn 2

Figure 3.68 4th prototype close up 1

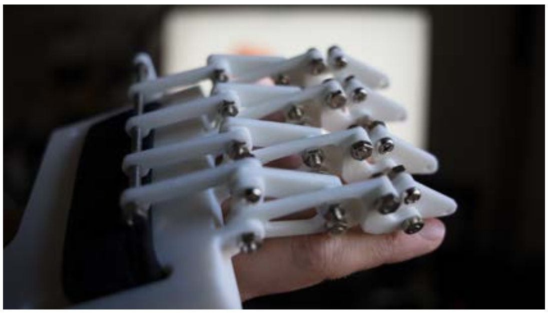

Figure 3.69 4th prototype finger exoskeleton close up 1

Figure 3.70 4th prototype finger exoskeleton close up 2

Figure 3.71 4th prototype wrist mechanism close up

3.8. Fifth Prototype

Base on the conclusion from the previous prototype, this prototype was designed to address the shortcomings of the last one.

3.8.1 Better palm fitting

To create a better fit for the hand, some modeling clay was moulded into a desired shape and put on the back of the hand and morphed to perfectly fit the contours of the back of the hand (Figure 3.72). Photos of the clay was then taken and imported into the CAD software for reconstruction/reverse engineering (Figure 3.73). Figure 3.74 and Figure 3.75 shows the 3D printed palm component closely resemble to the shape and dimension of the the clay model, but was thicker. The printed palm component were then put onto the back of the hand is test the fitting (Figure 3.76). The palm component fit the contours of the back of the hand perfectly but it was too thick and big. Adjustment was made accordingly with multiple exoskeleton finger attachment points and a palm strap slot as shown in Figure 3.79.

Figure 3.72 Modeling clay on the back of they hand

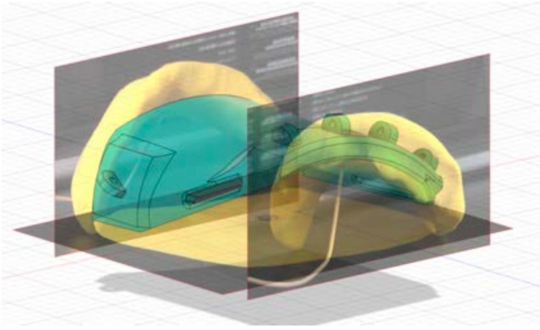

Figure 3.73 Reconstruction of the desired shape in CAD

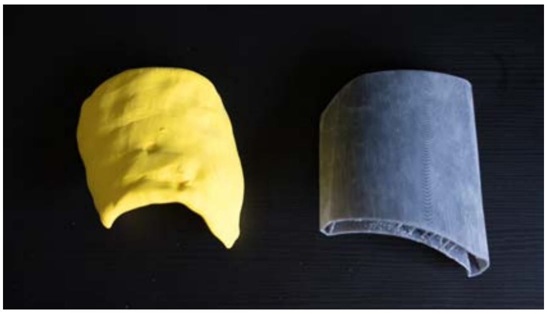

Figure 3.74 Left: Clay prototype; Right: 3D printed prototype (Top View)

Figure 3.75 Left: Clay prototype; Right: 3D printed prototype (Side View)

Figure 3.76 3D printed palm prototype fit test

Figure 3.77 3D printed finger prototype fit test

Figure 3.78 Palm and finger prototypes on hand

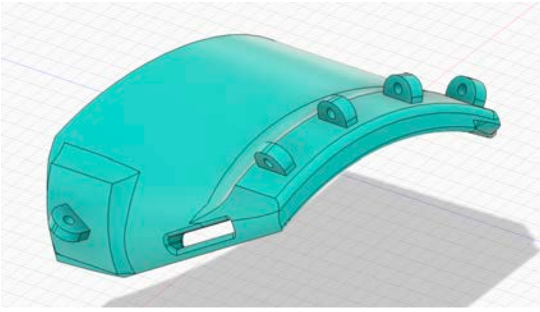

Figure 3.79 CAD drawing of modified palm component

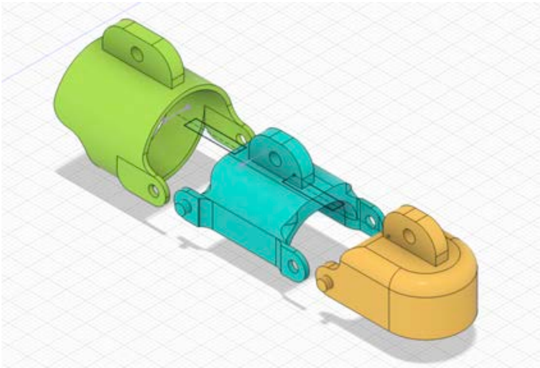

Figure 3.80 CAD drawing of new finger exoskeleton with individual phalanx

3.8.2 Better finger fitting

A new design for the exoskeleton finger was also designed in order to accommodate the individual movement of the MCP, PIP and DIP joints. The dimension of the fingers were measured and instead of using a four-bar linkage finger structure, each finger phalanx was given it's own exoskeleton part. The exoskeleton phalanx were then interlinked to mimic the PIP and DIP joints. The new design was printed and tested on the finger (Figure 3.77, Figure 3.78) and after a good fit is confirmed, attachment points were added to the design in CAD (Figure 3.80). The resulting exoskeleton finger fit very well to each finger and all fingers were allowed to move freely in all joints along with the exoskeleton.

3.8.3 Exoskeleton fitting

The entire exoskeleton assembly were then 3D printed and assembled and fitting onto the hand. This time the thumb was also included which is consist of two phalanxes (Figure 3.81). Figure 3.82 shows the hand wearing the exoskeleton in its extended position and Figure 3.83 shows it in the closed/grasp position.

Since the exoskeleton were designed based on my own measurements and therefore is not a surprise that it would fit my own hand, the exoskeleton was given to a second user to test how well it would fit other hands and the result is that it did fit. However it could just be that the second user have a similar hand size and dimension (Figure 3.84, Figure 3.85.

Figure 3.81 The new exoskeleton assembly

Figure 3.82 New exoskeleton assembly - extended position

Figure 3.83 New exoskeleton assembly - closed position

Figure 3.84 The exoskeleton assembly fitted onto a second subject's hand 1

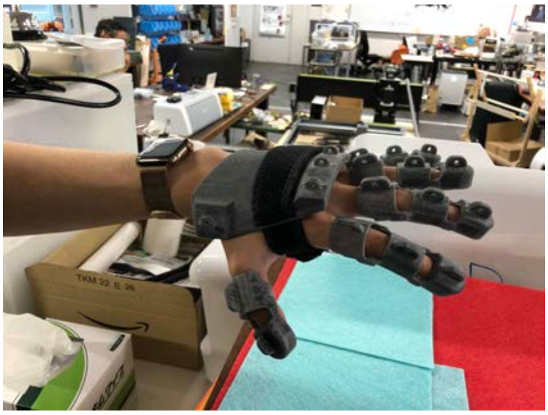

Figure 3.85 The exoskeleton assembly fitted onto a second subject's hand 1

3.8.4 Compliant Exoskeleton Test

The assembly still needs a backbone mechanism that drives the movement of the exoskeleton. Instead of using conventional bar-linkage type mechanism, a compliant mechanism backbone was designed and tested. The compliant mechanism is a monolithic structure with reduced material at the intended moving points. The mechanism was superimposed on to a photo of the assembly fitted onto the hand within the CAD software to determine its dimension and position as well required structure as shown in Figure 3.84.

The compliant backbone was 3D printed and fitted on to the exoskeleton assembly (Figure 3.88). However, the compliant backbone broke at one of the joints upon flexing. There are multiple contributing factors that caused the breakage. One is to do with the flexibility of the material. The material being used for the compliant backbone is the Tough 1500 Resin from Formlab. Although this material is already more pliable then the previously used Tough 2000 which has a lower modulus, the material is simply not pliable enough for the degree of motion that was intended for the mechanism. The second reason is the design of compliant mechanism itself. The compliant mechanism was designed based on intuition rather than the conventional finite element analysis method due to the lack of understanding on the subject matter. It was nevertheless a well intended attempt.

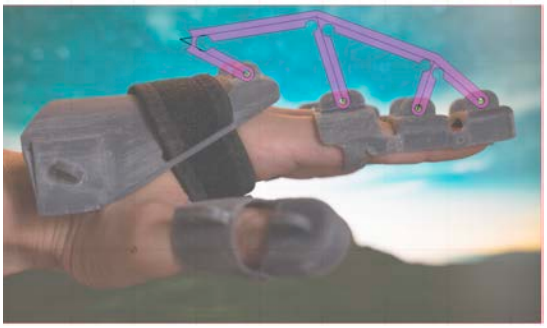

Figure 3.86 CAD drawing of compliant backbone

Figure 3.87 3D printed compliant backbone

Figure 3.88 Assembly with compliant backbone fitted on hand

Figure 3.89 Compliant backbone broken

3.8.5 Evaluation

The new exoskeleton has solved some of the issues from the previous prototype, which include a much better fitting of the hand which would help not only with the comfort but also the transfer of mechanical energy from component to component. The major hurdle to overcome is to add a backbone mechanism that would provide support for the bending of the fingers. Although an attempt was made using a compliant mechanism backbone, the design process of mechanism requires extensive knowledge in finite element analysis and the design process is usually very long. Considering the limited time frame of this thesis, the idea of incorporating compliant mechanism was abandoned at least for this stage of the development. A new exoskeleton structure which allows the individual movement of the MCP, PIP and DIP joints as well as one that also act as the driving mechanism of the bending movement would need to be developed.

3.9. Sixth Prototype

A new prototype which combined the driving mechanism of the finger bending movement and the finger exoskeleton components was designed. This time, only the index finger and thumb exoskeleton were developed as a proof of concept before expanding the design to other fingers since if the index finger mechanism works it is just a matter of copying the index mechanism to the other fingers with dimensional adjustments.

3.9.1 Index Finger Exoskeleton

The index finger exoskeleton is consist of six components. The blue component shown in Figure 3.90 act as a anchor point for the finger assembly as well as an attachment point to the palm component. When force is applied on the orange component as show in Figure 3.92, a closed position is achieved (Figure 3.93). This mechanism would be used to help drive the bending of the finger.

3.9.2 Thumb Exoskeleton

The thumb exoskeleton is consist of four components. The The index finger exoskeleton is consist of six components. The blue component shown in Figure 3.91 act as a anchor point for the finger assembly as well as an attachment point to the palm component. When force is applied on the orange component as show in

Figure 3.94, a closed position is achieved (Figure 3.95). This mechanism would be used to help drive the bending of the thumb.

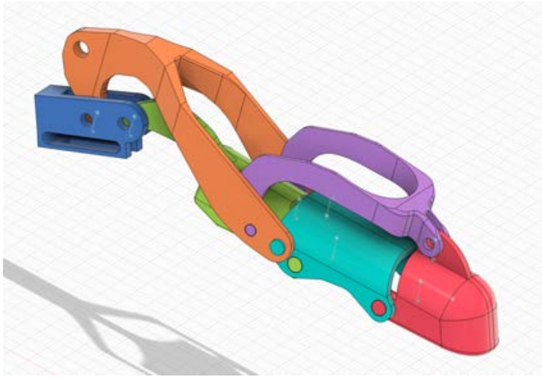

Figure 3.90 CAD drawing of index finger exoskeleton design

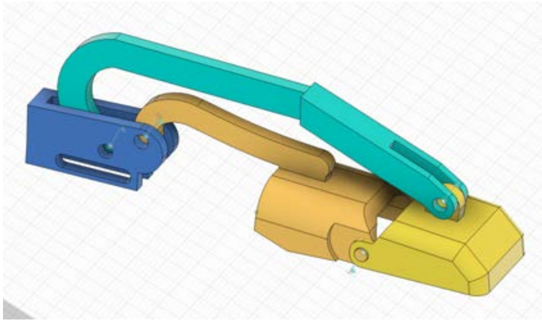

Figure 3.91 CAD drawing of thumb exoskeleton design

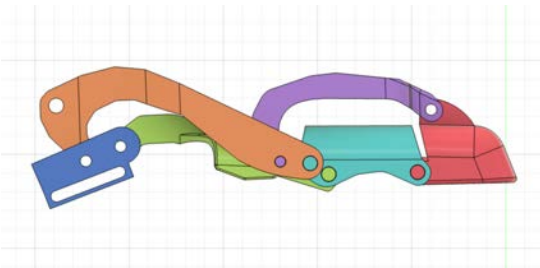

Figure 3.92 Open position of index finger exoskeleton

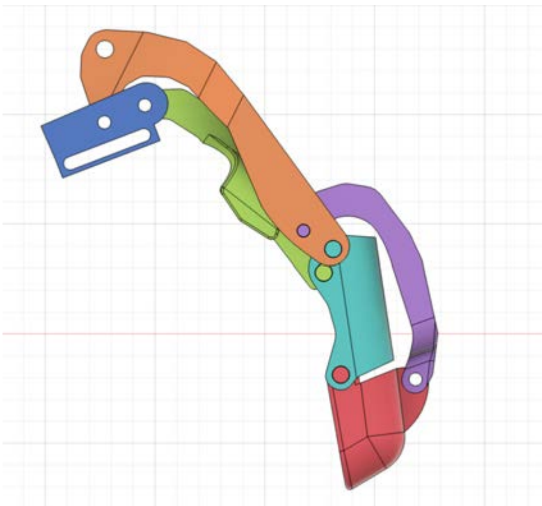

Figure 3.93 Closed position of index finger exoskeleton

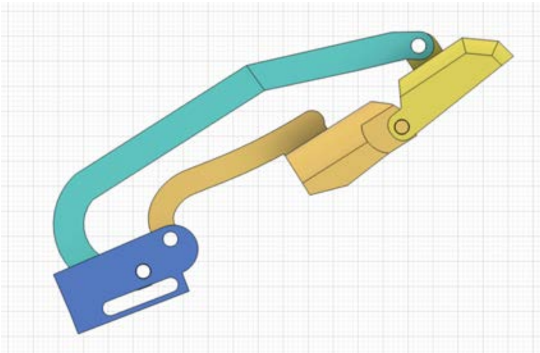

Figure 3.94 Open position of thumb exoskeleton

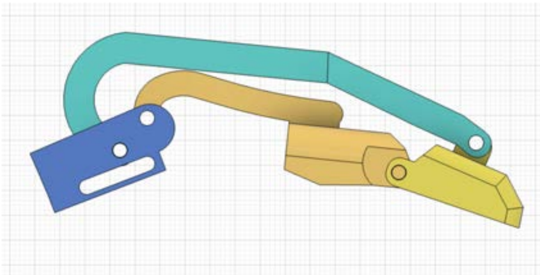

Figure 3.95 Closed position of thumb exoskeleton

3.9.3 Exoskeleton assembly

The index finger component and the thumb component were joined with the palm component is evaluation their relative positions in the assembly (Figure 3.96), Figure 3.97. The functionality of the mechanisms were simulated in the CAD software before proceeding to 3D printing.

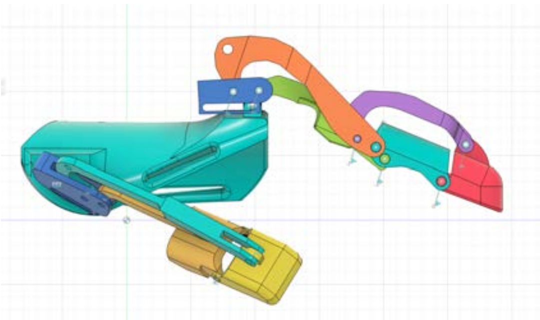

Figure 3.96 CAD drawing of exoskeleton assembly 1

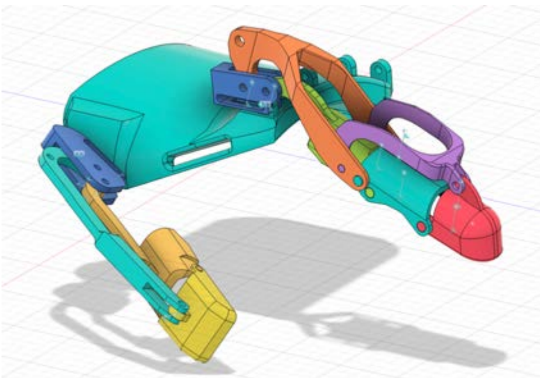

Figure 3.97 CAD drawing of exoskeleton assembly 1

3.9.4 3D Printed Results

The components were 3D printed with Formlabs Tough 1500 Resin (Figure 3.98). The results of the 3D printed components were less than satisfactory as there were a lot of dimensional errors as well as varied deformation. As shown in Figure 3.99, the thumb component underwent deformation and shrinkage causing the connection between the individual components become too tight. A second thumb component had residue resin accumulated within the inner surface of the slot, causing a bulge inside the slot which hindered the fitting of components (Figure 3.100). The thickness of a finger component was also inaccurate with an thickness of 3.42 mm instead of the intended 3 mm (Figure 3.101). Individual components were sanded down to allow for better connections (Figure 3.102).

The inaccuracy in dimension in the printed components might be due to some factors during the washing and curing procedures after the print. All prints are subjected to a washing process in a IPA(Isopropyl alcohol) bath which was followed by a UV curing process. It was later discovered the reason could be that the residue IPA on the printed material might not have let dried for long enough so that IPA were absorbed by the printed material during the curing process.

Figure 3.98 3D printed components on the build platform

Figure 3.99 Deformed thumb component

Figure 3.100 Bulge in printed component

Figure 3.101 Inaccurate dimension of printed component

3.9.5 Assembly and Fitting

The index finger exoskeleton was assembled and the mechanism functioned as simulated in the CAD software. Figure 3.103 shows the open position of the assembly and Figure 3.104 shows the closed position.

The entire exoskeleton were assembled and fitted onto the hand to test its functionality (Figure 3.105). The fitting was less than ideal as the connection point is located above the MCP of the index finger which put the centre of rotation of the joint between the finger and palm component too high above the MCP's centre of rotation, making it difficult to accommodate the finger movement.

The thumb mechanism also suffered from heavy deformation, making alignment with the thumb difficult (Figure 3.106. In addition, the size of the inner diameter of the index finger components were also too small to fit the index finger's phalanx (Figure 3.107). The finger tip part of the exoskeleton prevented the bending of the finger due to the fact that the finger will slide along and beyond the inner cavity of the exoskeleton, but the end cap of the exoskeleton prevent the finger from sliding forward (Figure 3.108). Adding to the existing problems, the exoskeleton is also misaligned with the index finger (Figure 3.109). Lastly, due to the many deformation of the individual components, the prototype structure fell apart, deeming unfit for user tests.

Figure 3.102 Sanding of individual components

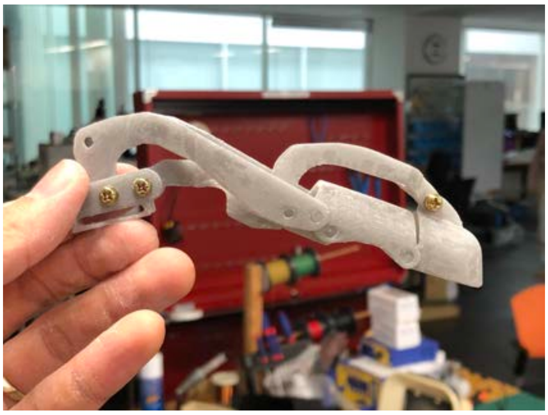

Figure 3.103 Index finger assembly open position

Figure 3.104 Index finger assembly closed position

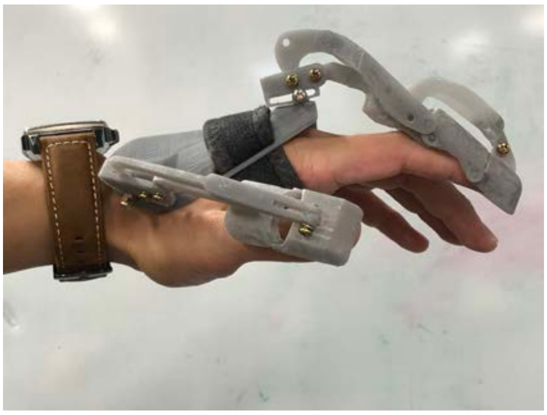

Figure 3.105 Exoskeleton assembly being worn

Figure 3.106 Deformation of thumb exoskeleton

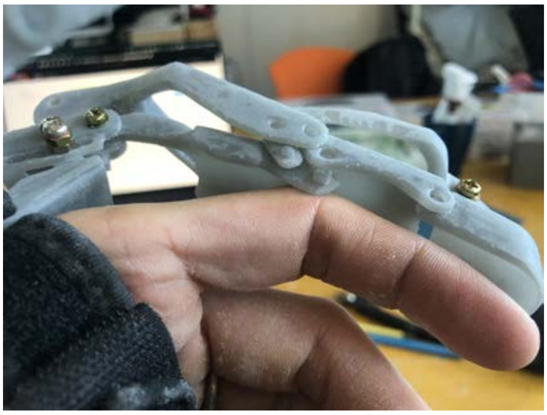

Figure 3.107 Diameter of exoskeleton too small

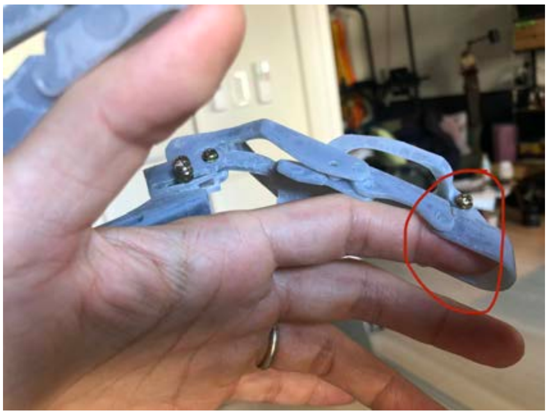

Figure 3.108 Finger cannot slide beyond the cap

Figure 3.109 Misalignment between finger and exoskeleton

Figure 3.110 Prototype falling apart

3.9.6 Second Iteration

A few modifications was made to the design. The index finger exoskeleton was directly incorporated into the palm component without the need of a connection component, lowing the centre of rotation of the mechanical finger to be closer to that of the user's MCP joint (Figure 3.111). The size of the finger exoskeleton was also increased to accommodate bigger fingers. Multiple supporting structures were added to individual components of the mechanical finger to reduce the effect of material deformation (Figure 3.112). The new design was then 3D printed with Formlabs Tough 2000 Resin which is more rigid than Tough 1500 to make the final product more durable for user testing (Figure 3.113, Figure 3.114).

3.9.7 Evaluation

The second iteration of the this prototype fit the finger and thumb much better than the last iteration (Figure 3.115). Although there is a misalignment in one of the holes between the finger and palm components (Figure 3.117), the problem was fixed by simply drilling a hole in the palm component (Figure 3.118).

The 3D printed components were assembled and fitted onto the hand. The fit was very good and all the mechanisms worked as intended and simulated in the

CAD software. And the prototype is finally rigid and durable enough for user testing.

All that is left is to design the wrist component that drives the entire exoskeleton.

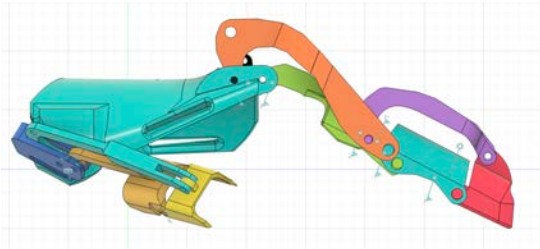

Figure 3.111 CAD drawing of 2nd iteration (side view)

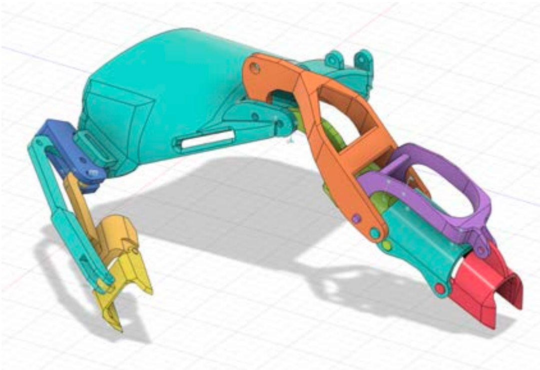

Figure 3.112 CAD drawing of 2nd iteration

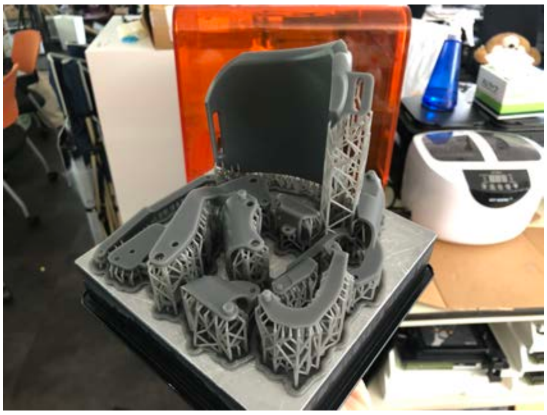

Figure 3.113 3D printed parts on printing platform

Figure 3.114 3D printed parts of 2nd iteration

Figure 3.115 Fitting of new finger exoskeleton

Figure 3.116 Palm and finger component joined

Figure 3.117 Misalignment between finger and palm

Figure 3.118 Hole drilled on palm component

Figure 3.119 2nd iteration fitted on hand 1

Figure 3.120 2nd iteration fitted on hand 2

Chapter 4
User Study and Evaluation

4.1. The objective of the test

One of the objectives of the user test is to gather feedback about the device in order to improve the device. Another goal is to let a number of users test use the device and observe anything that might standout during the test such as how the users interact with the device. It is also immensely important to scientifically quantify how effective the device is how using it might affect the user both mentally and physically.

4.1.1 TLX (Task Load Index) Test

The NASA developed TLX (Task Load Index) test is a workload assessment tool for assessing subjective workload for many human-machine devices. The TLX test has six sub-scales:

Physical Demand

This sub-scale, as it name suggests, assess how physically demanding a task is. For example, tasks that require pushing, pulling, twisting, etc.

Mental Demand

Mental demand assesses the cognitive demand of a task or the level of requirement of mental processing. There is a risk of affecting performance or making errors if the task requires a high level of mental demand. Some examples are thinking, calculating, remembering, searching, etc.

Temporal Demand

Temporal demand refers to the pressure exerted on the test subject that relate to the time constrains or time pressure of the task. A task with a high temporal demand might affect the operator's cognitive or physical performance when doing the task. Examples are having a quota as a goal or completing a task within a time limit.

Performance

Performance assesses how the operator perceive how well the task was done. For example how successful did the user complete the task set by the experimenter.

Effort

This sub-scale measures how much effort was required to complete the task at the level of performance that the task was completed.

Frustration

This sub-scale measures how insecure, discouraged, irratated, stress and annoyed versus secure, gratified, content, relaxed and complacent the user felt while completing the task.

The TLX test was used in this experiment to access the demand in workload in the aforementioned categories while using the proposed device when completing two simple tasks.

4.1.2 User Survey

A user survey was designed to assess several criteria that are important to the usability of the device:

1. Fitting - How well the device fits the user's hand. This has a direct effect on how well the device functions
2. Comfort - Measure the level of comfort while where the device. It is important to know if there is any discomfort while using the device

3. Weight - The user's perception of the weight of the device. This is an important data to collect to understand if the device is considered too heavy for the user. A heavy device would not be appealing to the user especially with this kind of hand assistive device.
4. Size - Similar to weight, the the perception of the size of the device will directly affect how likely a user would choose to use the device. The size of the device also correlates to how well the device might fit the user.

After completing the tasks, user were asked how difficult it was to complete each of the tasks when wearing the device.

4.1.3 Device Function Simulation Test

Since the proposed wrist-driven device is still in development stage without the wrist-driven functionality, a simulation test where the experimenter simulate the function of the device by manipulating the device i.e. applying force to the finger and thumb exoskeleton mechanism to simulate how both mechanism would be driven my the wrist mechanism (Figure 4.8).

Participants were then asked whether they could feel the device/exoskeleton were providing support by pushing their finger downward.

4.2. Test Setup

Tasks

The participants of this study were asked to complete two tasks:

1. Opening the cap of a water bottle (Thermos)(Figure 4.2, Figure 4.3)
2. Copying/drawing shapes that they can see from an example.(Figure 4.4, Figure 4.5)

Time Record

Participant were asked to perform the above tasks first without using the device and a second time using the device. The time it takes to complete each task were timed to compare if there is any effect on the time to complete the task with and without using the device.

Environment

The participants were seated at a table with a water bottle and a piece of paper with shapes (a triangle, a circle and a square) drawn as an example to copy from. They were also provided with a pen for the drawing task. The proposed device was also presented to the participant. A camera on a tripod was setup to video record the user tests (Figure 4.1).

Consent

Each participant were asked to sign a consent form when they have given their consent to take part in the user study.

Survey

The participants were asked to complete a written survey after completing the tasks (Figure 4.7).

TLX Test

The participants were asked to do the LTX test using the LTX app on a phone after completing the tasks (Figure 4.6).

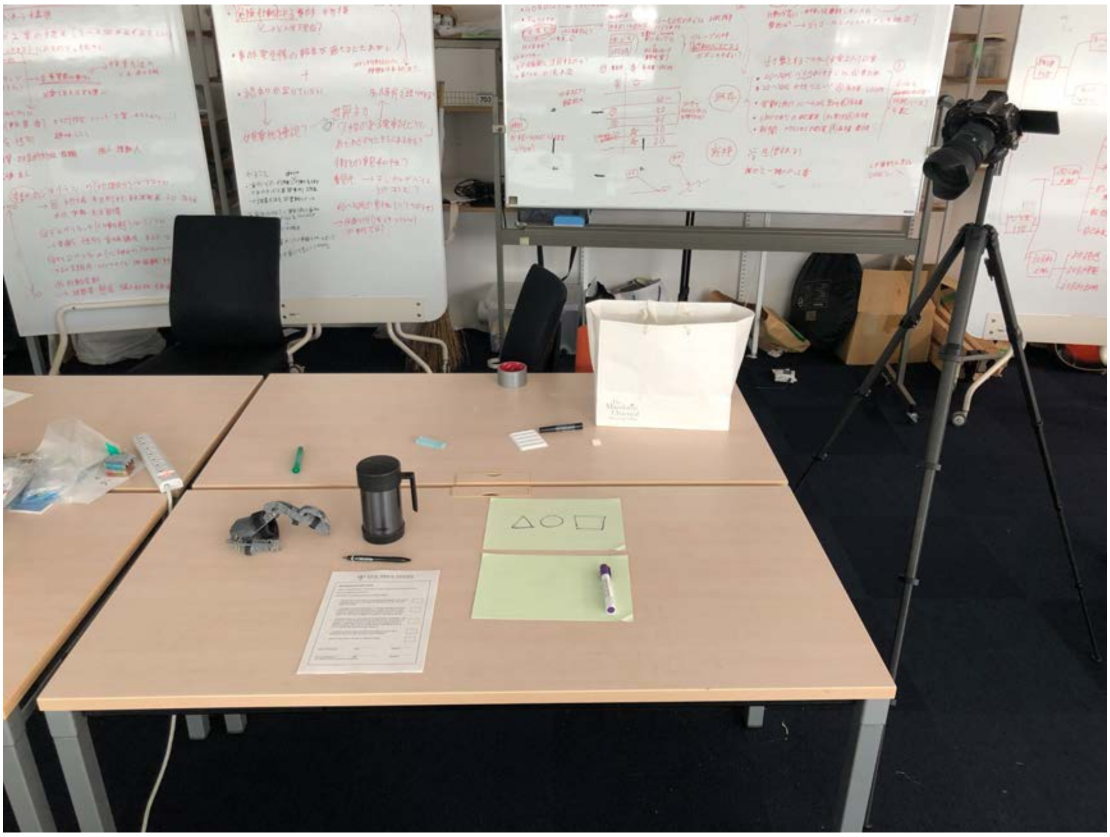

Figure 4.1 The user test environment

Figure 4.2 User performing Task 1

Figure 4.3 User performing Task 1

Figure 4.4 User performing Task 2

Figure 4.5 User performing Task 2

Figure 4.6 User doing LTX Test

Figure 4.7 User filling in survey

Figure 4.8 User undertaking simulation test

4.3. The Participants

The participants were picked randomly without targeting any particular group, gender or age (Figure 4.9).

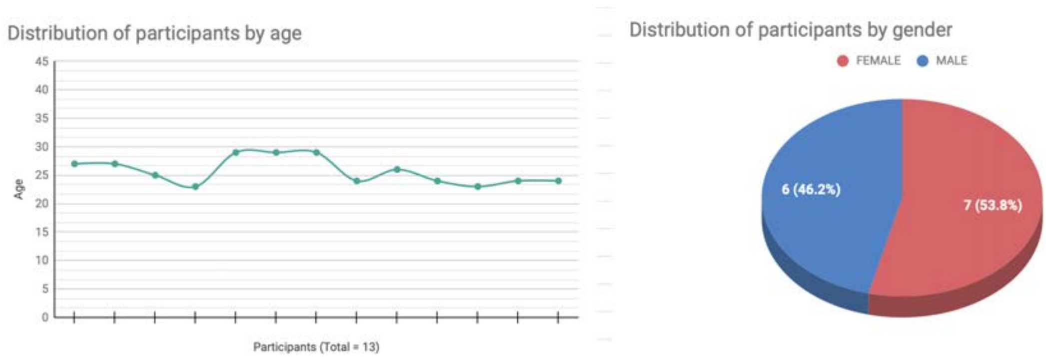

Figure 4.9 Participants information

4.4. Results and evaluation

4.4.1 Survey Results

The overall results of the survey is shown in Figure 4.10

Fitting

The results from the survey and the comments that made by the participants is that the device in general did not fit their hand well (Figure 4.11). This is understandable and expected as the prototype was modelled after the experimenter's hand and hand sizes varies between individuals, let alone age, gender and other genetics factors. Many suggested making the device customisable or with varied sizing to accommodate a broader range of hands sizes.

Below are some comments made by the participants when asked what could be improved:

"Maybe make it adjustable so that it would fit any wearer's hand (change on the fly)"

"I think if the exoskeleton would be custom fit to each hand it would be an effective device!"

"Availability of different sizes"

"サイズが調整できるとよいです (It would be great if the size can be adjusted.)"

"Size. Better fitting around the PIP area"

Comfort

In terms of comfort, the finding seems to be a bit neutral. The participants did not seemed to have experienced any discomfort while using the device bit neither did they think that it was very comfortable to wear the device. Since the device is designed for prolonged usage, it is important that all users did not report of any discomfort while using the device (Figure 4.12).

Weight

The majority of participants considered the device light in weight. Which is a positive feedback as such a device that is designed to be portable and worn for a prolonged period needs to light weight to prevent fatigue from using the device (Figure 4.13).

Size

The majority of the participants considered the device too big (Figure 4.14). This could be the result of the varied hand size of different participants, similar to the evaluation for "Comfort", a device that can have adjustable size would be ideal in the future.

Ease of Tasks with the device

According to the survey results (Figure 4.15), most participants found completing task 2 (drawing) relatively easier than task 1 (opening the cap of a bottle). This could be contributed by the fact that opening the cap of a bottle require more finger movement and finger dexterity, wearing the device might have restricted the user's fingers' range of motion. In the future, a device that would allow full range finger motion would be desired.

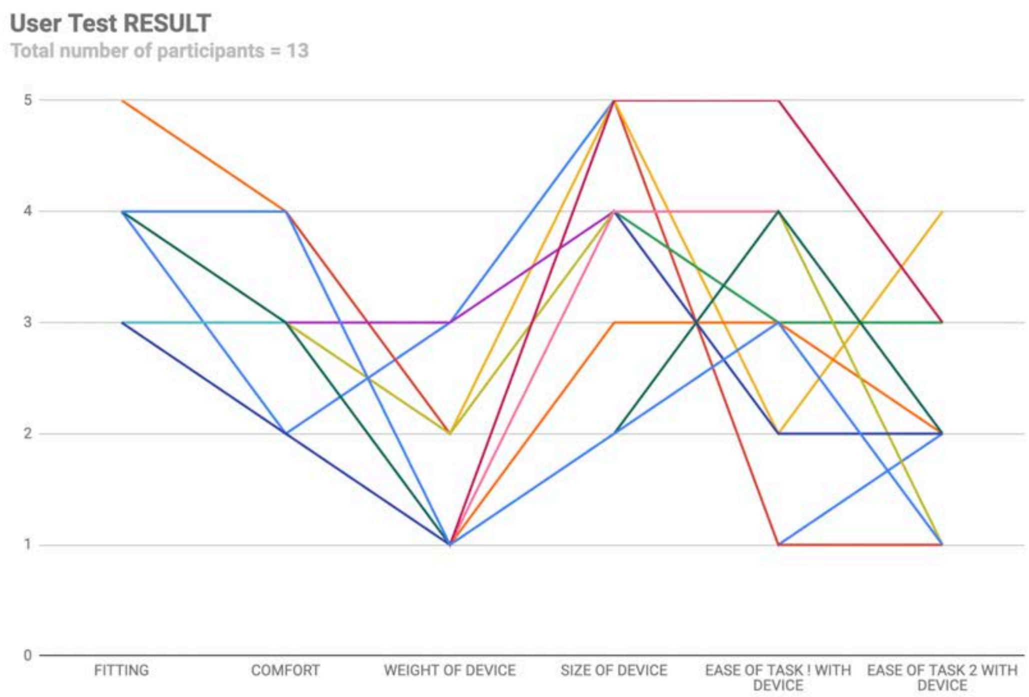

Figure 4.10 Overall Survey Results

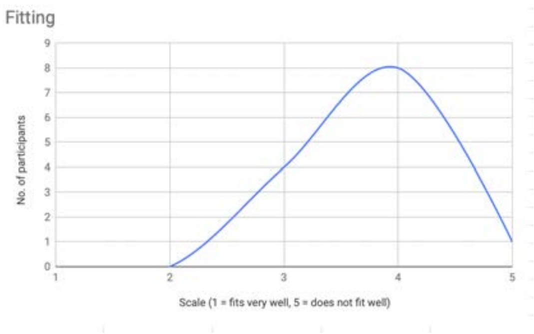

Figure 4.11 User rating for Fitting

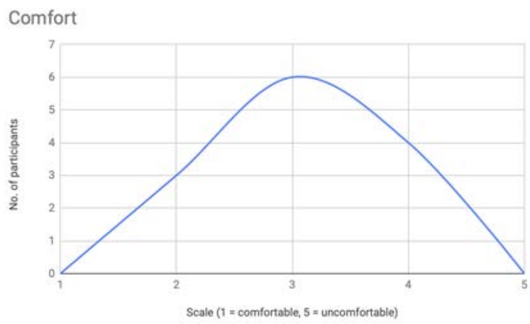

Figure 4.12 User rating for Comfort

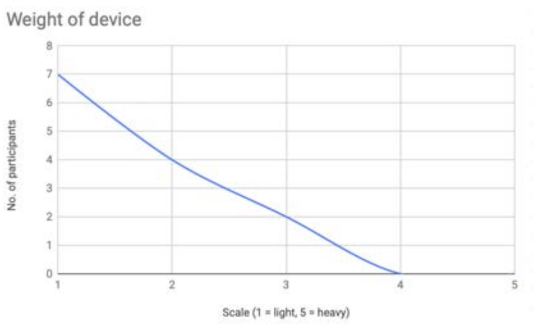

Figure 4.13 User rating for Weight

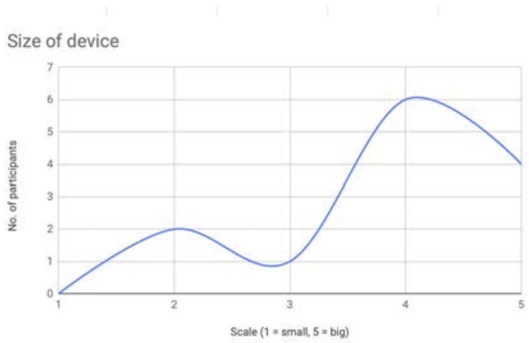

Figure 4.14 User rating for Size

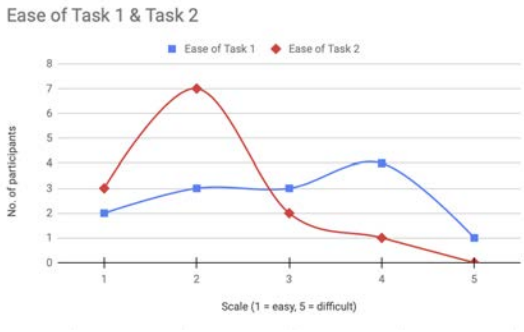

Figure 4.15 User rating for Task 1 and 2

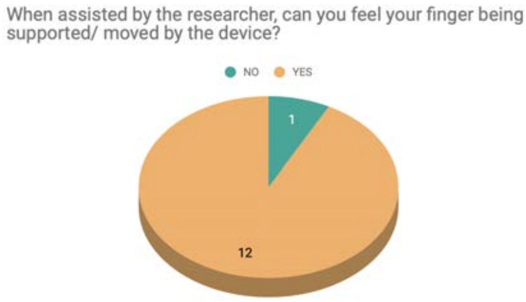

Figure 4.16 Simulation Test Results

Time Record for completing Task 1 and 2 with and without the device

The time for completing Task 1 and 2 with and without using the device were recorded to see whether using the device or not would affect the ability to complete the task. For Task 1, the results suggested that wearing the device hinders the participant's ability to complete the task as the time taken when using the device is consistently longer than the time taken without the device (Figure 4.17. The results suggested that the device needs improvements as it is an assistive device which is supposed to enhance one's ability to complete tasks rather than hindering it. Although this device targets individuals with hand impairment or reduced hand motor functions and the participants are healthy individuals with normal hand functions, more studies need to be conducted.

For Task 2, the time taken to complete the task did not seem to be affected by the use of the device as no major trend can be seen in the comparison (Figure 4.18). There are even instances where user completed Task 2 faster with the device. However, due to the nature of the test which is to draw different shapes on a piece of paper, it is a task that does not require much finger movement but rather arm movement, wearing the device might not make a difference in the ability to complete Task 2. The reason for using shorter time to complete Task 2 could well be because the participants have had "practice" in completing Task 2 without the device before they do the same task with the device, allowing them to be a bit more familiar with the task.

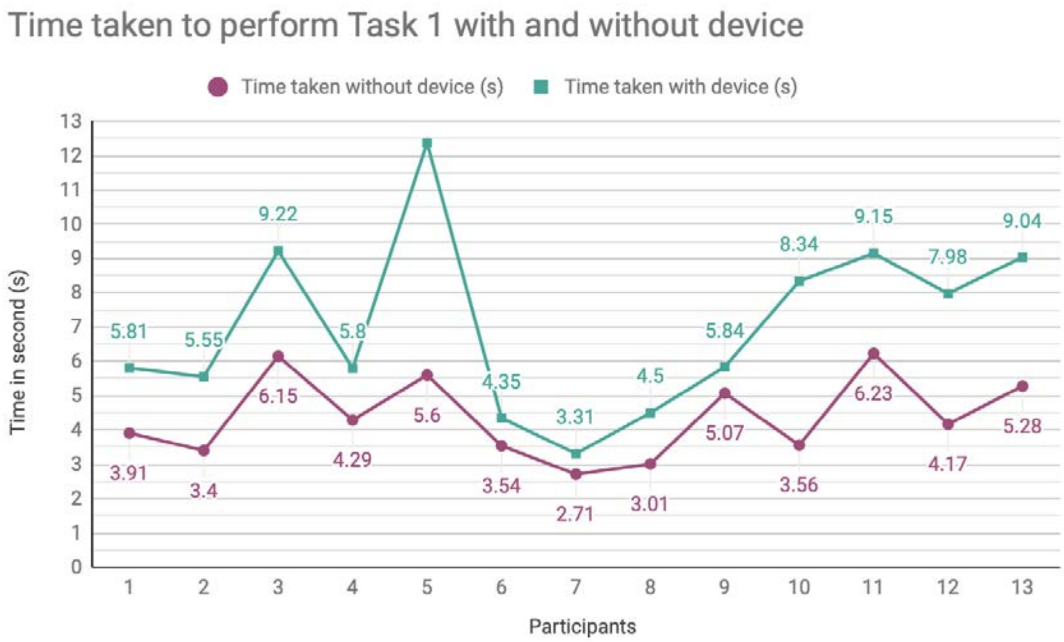

Figure 4.17 Time record for Task 1

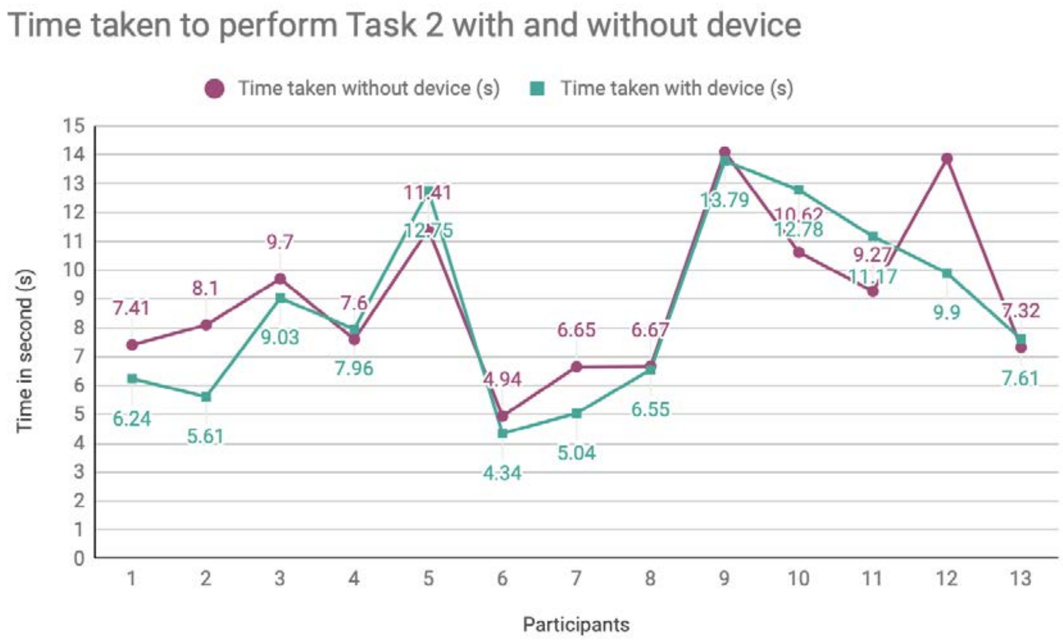

Figure 4.18 Time record for Task 2

Simulation Test Result

According to the result, 12 out of 13 participants could feel that the device had helped with the flexion of the finger. However, what was missed out in the survey was whether the participants had felt the support providing by the device in both the index finger and the thumb as from the user test observation, most participants' thumb were not able to move much because the device restricted their thumb movement due to a poor fit. Nevertheless, the results provided valuable insights for the next prototype design.

Other Comments from the participants

"Make it more "invisible" so that people won't feel like they are using a device/ people won't notice them as using a device"

"The device is a little bit big and also it's for the left hand. I would also like to try one for my right hand "

"MCP - PIP distance too long. Thumb rotation axis needs improvement"

"Size. Better fitting around the PIP area"

4.4.2 TLX Results

Figure 4.19 shows the rate distribution across different sub-scale/categories of the LTX. The consensus from the result seem to be that the device is not demanding in all categories as most rating are below 50. There are, however, some out-liners that went as high as 70. That out-liner result is from a participant who speaks Japanese as the mother-tongue. As the LTX is in English, the participant did have some difficulties understanding the terms like Mental Demand, Temporal, etc. It could also be the fact that every individual perceive a scale differently i.e. one may consider a rating of 60 out of 100 fairly low and one more consider it extremely high. Nevertheless, although the LTX results cannot be entirely relied on, it serves as a source of insights for the future design of the device.

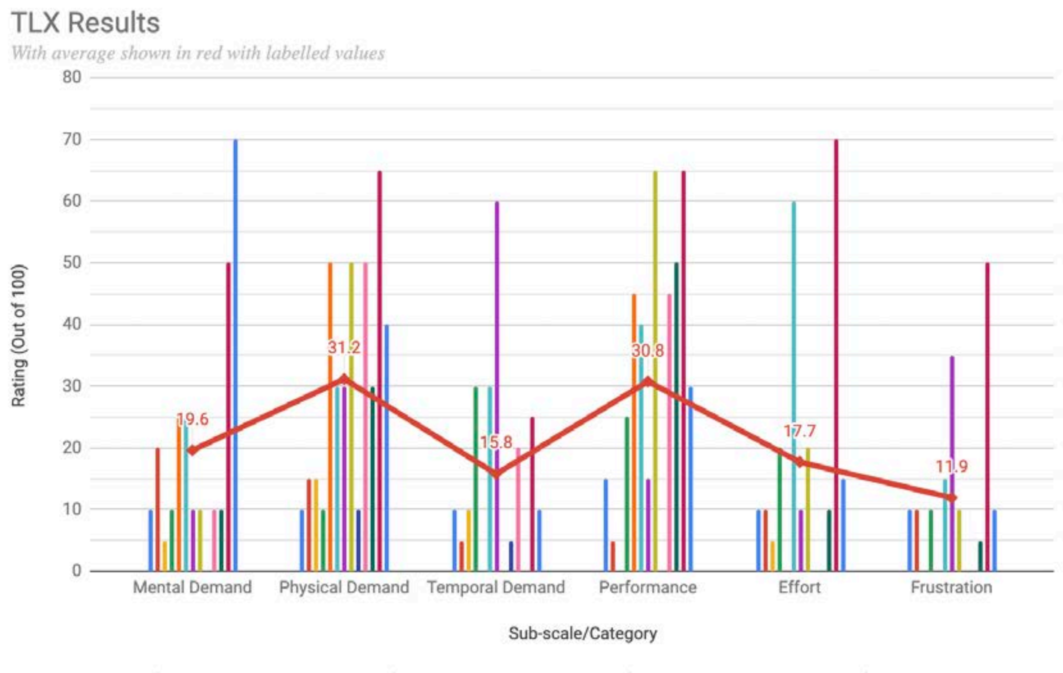

Figure 4.19 TLX Results

4.5. Target User Test and Interview

Within the group of participants, one of the individual is a target user with reduced hand motor functions and weak hand grip strength. The individual was interviewed to gather feedback and opinion about the proposed assistive device.

Having reduced hand motor functions and weak HGS had affected her on a daily basis. It affect doing simple chores like cutting food with a knife, washing utensils and dishes, using a frying pan, etc. whenever she needs to use grip strength to complete tasks, not only that she is not able to use force and grip things, when she does she would feel pain. She also suffers from hand tremor which limits her ability to do things that she likes such as sewing. She is not using any assistive at the moment and had not used any previously. However, when she asked about whether the proposed device would help with her condition she said she would like to try (The wrist-driven assistive device).

She also mentioned that it would be great of the proposed assistive device could also act as a resistance training tool.

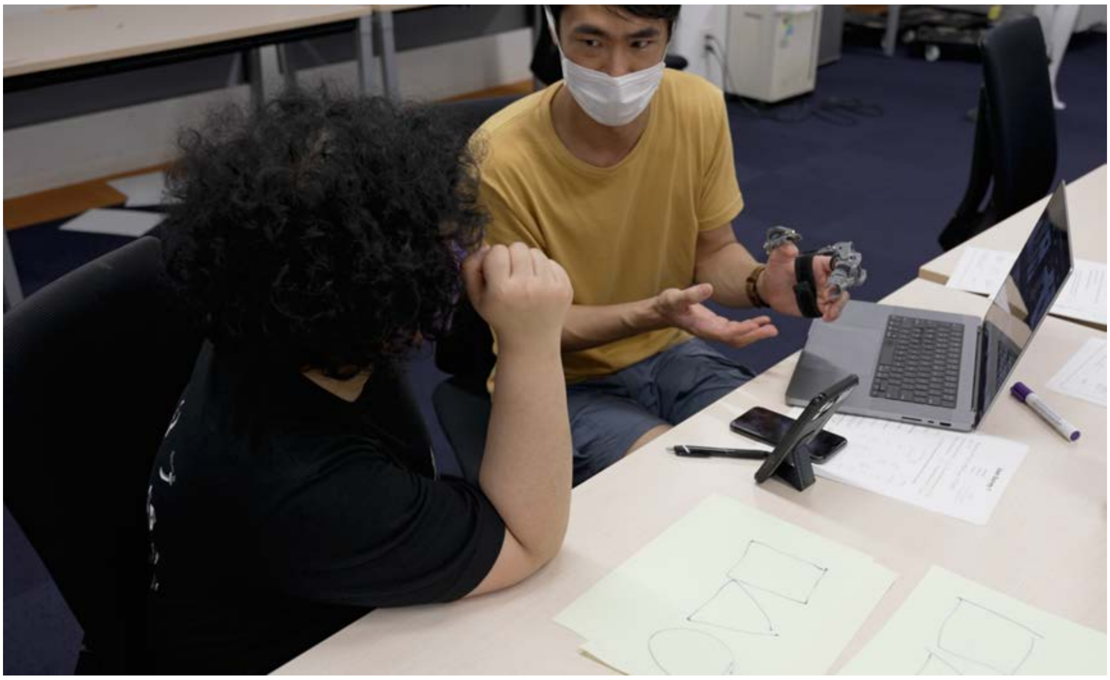

Figure 4.20 Target user interview

Figure 4.21 Target user interview

4.5.1 Second Target User Test (Shadowing)

In the second target user test, instead of asking the the participant to fill out a survey, the participant was being shadowed for half a day in order to observe how the user interact with, and use the device throughout the day(Figure 4.22, 4.29). This is a more open approach to collect more in-depth insights about using the device by observation rather than asking predetermined questions. Throughout the day the user performed daily tasks such as ripping off food packaging (Figure 4.26) and peeling shells of the egg food during breakfast (Figure 4.27), opening the zipper of a backpack to get a laptop out(Figure 4.28), to using smaller objects like a lighter(Figure 4.29).

Observation Results

The following are some of the key findings from the shadowing user test:

1. In various situations such as typing on the keyboard, and things that requires fingers dexterity, the device is limiting rather than helping.
2. The size of the device still needs to be customised to the user ' s hand.
3. With the device connecting the wrist and the hand, it somehow helped with hand tremor. Stabilising the hand.
4. The device limits certain hand movements such as the fanning of the fingers.
5. The device gets in the way of wearing accessories like a watch.
6. The user loves the device and thinks it is really cool to wear it.

The human hand is a very complex "device" in itself which is able to perform very complex finger movements and with all the different joints combined, move in many degrees of freedom. Any form of exoskeleton type device that is being put on the hand is destined to restrict its range of movement, and there is no exception of the proposed device. And due to the fact that the exoskeleton was modelled after my own hand, it simply could not fit the different contours and shapes as well as size of everyone. Owing to this fact, the ideal user test would need to first measure the hand of the users and custom make the device to fit their hands as much as possible. Perhaps the most surprising finding was that the device was able to stabilize the user's tremor. The wrist component connecting to the palm component acted as a "anchor" for the user's hand during tremor, limiting the level of tremor. However, the same structure also restricted the twisting movement of the wrist as reported by the user. Another finding was that the user find the device really cool and that she really enjoyed wearing because it made her feel like a cyborg, or Ironman. This is very important as part of the goal is to create something that is not only functional, but also something that the user would enjoying using instead of something that they would feel embarrassed wearing or something that would affect their ego because it reminds them of their inability. The more comfortable the user find when wearing the device the longer they could wear it for which assistive the user on a daily basis as well as aiding their recovery.

Figure 4.22 User shadowing 1

Figure 4.23 User shadowing 2

Figure 4.24 User shadowing 3

Figure 4.25 User shadowing 4

Figure 4.26 User shadowing 5

Figure 4.27 User shadowing 6

Figure 4.28 User shadowing 7

Figure 4.29 User shadowing 8

Chapter 5
Conclusion

Problems related to hand impairment, reduced hand motor functions and weak grip strength are difficult to solve as the hand is an extremely complex body part and hand motor functions has a lot more contributing factors other than muscles strength alone, such as finger dexterity. The proposed wrist-driven hand assistive grip device is not attempting to solve all hand motor function/ grip strength related conditions but rather act as an alternative hand assistive device that unlike many products on the market that requires actuators and tethered power supply to function. It aims to provide an affordable, 3D printable, accessible, portable alternative that harnesses the power from the wrist to aid performing daily tasks. Although it has yet to be tested, the proposed device could also be a potential rehabilitation tool without the shortcomings of the existing products.

It is extremely difficult to validate the usefulness of the proposed device from the limited user tests carried out in this thesis. The device is still in a very early stage of development and a lot of work are yet to be done to bring the device to fruition. Rather, this thesis aims to inspire others to explore the possibilities and potential of a body-part-driven assistive device to benefit those who are in need.

5.1. Limitations

The wrist-driven device in this thesis merely act as a proof of concept with the following limitations:

Wrist Impairment

Since the proposed device is a wrist-driven hand assistive tool, individuals with wrist impairment would not be able to use this device. As a matter of fact, many hand impairments or reduced hand motor functions also suffer from reduced wrist motor functions as the wrist is an integral part of the hand (insights obtained from an interview with a physiotherapist). Therefore this wrist-driven device would only be able to benefit those who have reduced hand motor functions but still have normal wrist motor functions.

Finger Coverage

In this thesis, the device only covers the index finger and the thumb. For most daily activities the use of all fingers are required. At this early stage of development, the device is yet to be able provide any meaningful daily assistance to its user. More work will need to be done to expand the functionality of the device to incorporate support for all fingers.

Full range hand motion

The proposed device only move the finger in one degree of freedom. But in reality the human finger is so complex and are able to move in many degrees of freedom. Motion such as fanning of the fingers would not be supported by the device, let alone functioning while the hand is in a fanned position. The human hand and fingers are so complex and dexterous that a more complex device would have to designed to accommodate all the complex movements that the human hand is capable of.

5.1.1 Psychological and social impact of reduced hand motor function

Although the primary aim of the preliminary research was to identify how reduced hand motor functions affect daily activities on a physical and mental level, the research results has shown that it could even have social impacts.

Psychological Impact

There seems to be a lack of research on the psychological impact of reduced hand motor functions upon literature review. According to the survey results, when an individual is unable to perform tasks on their own, it ruins their mood and cause frustration. Though only 14.8% of surveyees said they it ruins their mood and 25.9% said that it frustrates them, while the majority (55.6%) said they it does not bother them at all, it could actually be the reason why psychological impacts are often overlooked due to our tendency to put resources and solve problems that are only shared by the majority(Figure 3.7). That is not to said that modern society ignores the needs of the minority, but especially when it comes to the economical viability, resources do tend to flow into solutions to problems that concern larger populations. Not only that these impact on mood and cause frustration, chronic experiences of such could be contributing factors of more severe mental health issues. Hopefully more research could be done in this aspect which could uncover correlations between not just reduced hand motor function and mental health issues, but between physical disabilities and mental health issues in general.

Social Impact

Similar to the psychological impact of reduced hand motor function, the inability to perform daily task or participate in social activities could have significant impact. If an individual has reduced hand motor function, he/she might not be able to participate in social activities. An good example is when an elderly adult with weak hands were unable to participate in a recreation therapy drawing session because he could not even hold a pen. And this is only one of the examples which led us to think of this problem on a larger scale. The lack of social participation could potentially lead to more serious mental health issues that if left unchecked, add mental disabilities on top of the already detrimental physical disability.

5.2. Future Works

To make the device more flexible, lighter and capable, perhaps alternative materials, structures or mechanisms would need to be developed.

For future development the device need to include all fingers of the hand and, if possible, make it so that the size of the device is adjustable on the fly so that it does not need to be custom made to each user, hence further reduce the cost.

More user tests and clinical trials need to be carried out to see if the device could be more than an assistive device, but a rehabilitation device to help its user regain hand motor functions.

Current devices including the proposed device in this thesis still relies on mechanical hinges and joints to function, which add weight, part counts and the need for assembling to the device. In the future, it would be great if such device could be made with a compliant mechanism design where the device is monolithic device that could be 3D printed as a single piece of material.

With future advancements in technology, maybe a hand assistive device the resembles a glove that is completely made of special fabrics with compliant mechanisms weaved into the fabrics could be developed.

More research should be also be done in regards to the psychological and social impact of physical disabilities. Again, no research could tell you about the embarrassment one experiences when they need to ask someone else to wash their body for them, or even something as simple as asking someone to cut their toenail for them. These small instances of embarrassment are common and they add up, but it is also because of how small they seemed that caused them to be overlooked.

Assistive devices need to not only provide physical support for the user, but also take into account to psychological effect of using the device on the user. Designers of assistive devices need to be mindful of the psychological impact of the usage of the devices and make designs that make its users feel empowered and even bring joy to them.

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Appendices

A. Elderly Care Centre Survey

KEIO MEDIA DESIGN

慶應義塾大学大学院メディアデザイン研究科

KEIO UNIVERSITY GRADUATE SCHOOL OF MEDIA DESIGN

免責事項：

この研究の目的は、高齢者の握力不足と日常生活への影響を調査することです。この研究は、慶應義塾大学大学院メディアデザイン研究科の大学院生であるモック・カー・キットが行っている研究プロジェクトです。本調査の対象者（70歳以上）に該当するため、本調査に参加いただくことになりました。

この研究プロジェクトへの参加は任意です。参加しないことも可能です。この研究調査に参加することを決定した場合、いつでも撤回することができます。

手順としては、約30分ほどで以下のアンケートに回答して頂きます。回答は機密扱いとなり、名前や住所など個人を特定する情報は一切収集致しません。アンケートの質問は、手で何かをするときに直面する問題と握力に関して、また、握力が不足している場合に日常生活にどのような影響があるかに関してです。

この調査で収集された情報は、学術的な目的および将来的な新規ツールの開発に使用されます。この調査研究に関するご質問は、colinmok@keio.jp までご連絡ください。

あなたは、この研究調査に参加することに同意しますか？
- ☐ 同意する
- ☐ 同意しない

<u>アンケートの仕方</u>

該当するものをボックスにチェックしてください

例：
作業をするときに他の人にお願いすることが多いですか？
☐ 多い
☑ 時々
☐ あまりない

例：
あなたは、次のような作業をすることが困難だと感じますか？

<手足の爪切り>
☑ 困難に感じる(具体的にお書きください：
足の爪を切るときに屈むことができない＿＿＿＿＿)
☐ 困難に感じない

1. あなた自身の指先は器用(指を使って小さな物を扱ったり、物を操作すること)ですか?

- ☐ 非常に器用である
- ☐ やや器用
- ☐ 普通
- ☐ 器用ではない

2. 最近、手先を使う作業で困ったことはありますか？

- ☐ はい
- ☐ いいえ

3. 手先を使った作業に困難する頻度はどのくらいありますか？

- ☐ いつも（毎日）
- ☐ ほとんどの場合（ほぼ毎日）
- ☐ 時々（週に数回）
- ☐ まれに（1ヶ月に数回程度）
- ☐ 全くない

4. あなたの握力は強いと思いますか？

- ☐ 強いと思う
- ☐ まあまあ強いと思う
- ☐ 普通だと思う
- ☐ 弱いと思う

5. あなたは、次のような作業をすることが困難だと感じますか？

<瓶を開ける>

☐ 困難に感じる(具体的にお書きください:

____)

☐ 困難に感じない

困難に感じてるときにどうしますか？

☐ できる限りやってみる

☐ 誰かにお願いする

☐ 諦める

☐ 補助具を使う

（何を使いますか？例：輪ゴム______________________）

図：瓶を開ける補助具。

写真に記載している補助具を使ったことがありますか？

☐ ある

☐ ない

<プルタブ缶の開封>

☐ 困難に感じる(具体的にお書きください:

____)

☐ 困難に感じない

困難に感じてるときにどうしますか？

☐ できる限りやってみる

☐ 誰かにお願いする

☐ 諦める

☐ 補助具を使う

（何を使いますか？_______________________）

図：プルタブ缶の開封用補助具。

写真に記載している補助具を使ったことがありますか？

☐ ある

☐ ない

<ドアノブを回す>

☐ 困難に感じる(具体的にお書きください:

____)

☐ 困難に感じない

困難に感じてるときにどうしますか？

☐ できる限りやってみる

☐ 誰かにお願いする

☐ 諦める

☐ 補助具を使う

（何を使いますか？______________________________）

図：捕まりやすいため、ドアノブにつける補助具。

写真に記載している補助具を使ったことがありますか？

☐ ある

☐ ない

<服を着る>

☐ 困難に感じる(具体的にお書きください:

____)

☐ 困難に感じない

困難に感じてるときにどうしますか？

☐ できる限りやってみる

☐ 誰かにお願いする

☐ 諦める

☐ 補助具を使う

（何を使いますか？______________________________）

図：靴下を着る補助具

写真に記載している補助具を使ったことがありますか？

☐ ある

☐ ない

<歯を磨く>

☐ 困難に感じる(具体的にお書きください:

____)

☐ 困難に感じない

困難に感じてるときにどうしますか？

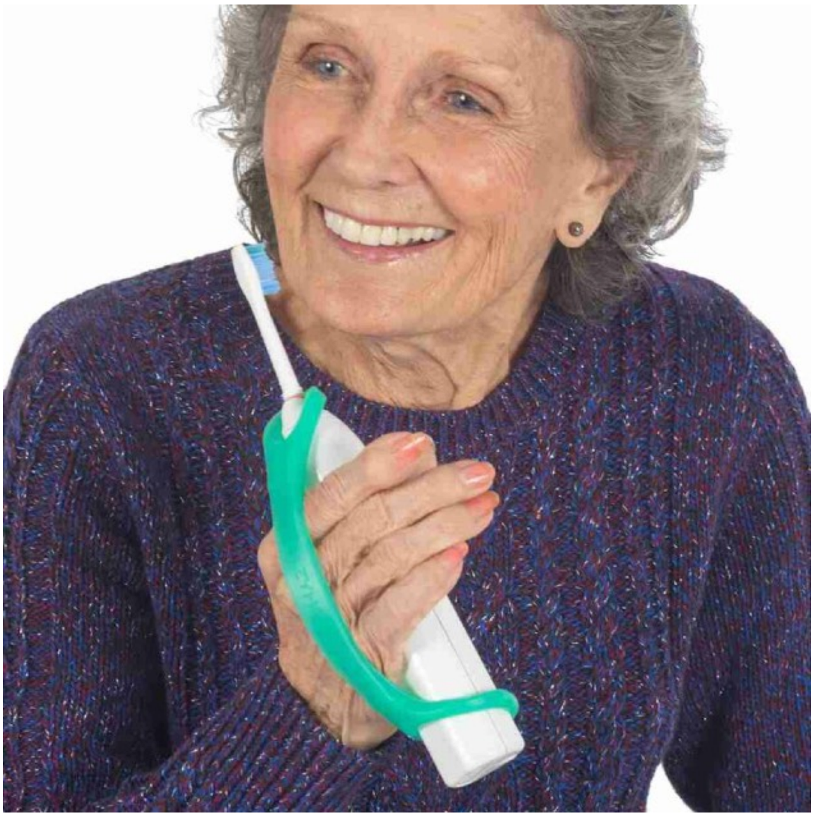
☐ できる限りやってみる

☐ 誰かにお願いする

☐ 諦める

☐ 補助具を使う

（何を使いますか？___________________________）



図：捕まりやすいため、ハブラシにつける補助具。

写真に記載している補助具を使ったことがありますか？

☐ ある

☐ ない

<アクセサリーを身につける>

❏ 困難に感じる(具体的にお書きください:

____)

❏ 困難に感じない

困難に感じてるときにどうしますか？

❏ できる限りやってみる

❏ 誰かにお願いする

❏ 諦める

❏ 補助具を使う

（何を使いますか？______________________）

図：腕輪をはめる補助具。

写真に記載している補助具を使ったことがありますか？

❏ ある

❏ ない

<料理（食材の下ごしらえ>

☐ 困難に感じる(具体的にお書きください:

____)

☐ 困難に感じない

困難に感じてるときにどうしますか？

☐ できる限りやってみる

☐ 誰かにお願いする

☐ 諦める

☐ 補助具を使う

（何を使いますか？______________________________）

図：高齢者向き調理器具

写真に記載している補助具を使ったことがありますか？

☐ ある

☐ ない

<手足の爪切り>

☐ 困難に感じる(具体的にお書きください:

____)

☐ 困難に感じない

困難に感じてるときにどうしますか？

☐ できる限りやってみる

☐ 誰かにお願いする

☐ 諦める

☐ 補助具を使う

（何を使いますか？______________________________）

図：長い柄の足の爪切り

写真に記載している補助具を使ったことがありますか？

☐ ある

☐ ない

6. ＜５.＞のような作業ができないとき、どのような気持ちになりますか？ (複数選択可)

☐ 自尊心が低下する
☐ 気分が滅入る
☐ イライラする
☐ 全く気にならない
☐ その他＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿

7. ＜５.＞のような作業が自分一人ではできない場合、次のうちどれが一番適していると思いますか？

☐ 補助具を使ってでも、何でも自分でやろうと思う。
☐ 誰かの負担になりたくはないが、助けを求めるしかない。
☐ 他人の助けが必要だが、恥ずかしくて助けを求めないことがある。

8. 補助具を使うとき、どのような気持ちになりますか？

☐ 補助具から力を貰った気がする
☐ 補助具がないとできない自分を思い知らされたような気がする
☐ 補助具を使わなければならないのが、もどかしい
☐ 特に何も感じない
☐ その他＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿

9. 今使っている補助具に不満はありますか？どんな不満がありますか？

____

____

____

____

10. もし、指先の器用さや握力を高めて、複数の補助具を使わずにどんな作業でもできる装置があったら、どう思いますか？

- ☐ 利用したい
- ☐ 試してみたい
- ☐ 複数の道具を使い分けることに抵抗がない
- ☐ どちらかというと、人に手伝ってもらいながら作業をしたい。
- ☐ その他___________________________________

11.どのような作業をサポートするツールにしたいですか？日常生活で一番困っていることは何ですか（例：歩く)

12.年を重ねて良かったと思うこと、現在の年齢になって改善されたと思うことはありますか？

13.現在の年齢になって良かったと思うことは何ですか？

アンケートにご協力いただき誠にありがとうございました

B. User Test Survey

User Survey 1

	Researcher:	Mok Ka Kit
	Institution:	Keio Graduate School of Media design
	Research:	A Wrist-driven Hand Exoskeleton Grip assistive Device

Participant Name:	Gender:
Age:	
Time taken without device (Task 1):	Time taken without device (Task 2):
Time taken with device (Task 1):	Time taken with device (Task 2):

On a scale of 1 to 5, please pick the most suitable value for each question.

Fitting	does not fit well				fits very well
	1	2	3	4	5
Comfort	uncomfortable				comfortable
	1	2	3	4	5
Weight of the device	light				heavy
	1	2	3	4	5
Size of the device	small				big
	1	2	3	4	5
Ease of Task 1 with device	easy				difficult
	1	2	3	4	5
Ease of Task 2 with device	easy				difficult
	1	2	3	4	5
Device function simulation Test					
When assisted by the researcher, can you feel your finger being supported/moved by the device?	No		Yes		
What can be improved about the device?					

C. Consent Form

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Participant Consent Form

Title of research project: A Wrist-driven Hand Exoskeleton Grip Assistive Device

Name of researcher: Mok Ka Kit

Department: Keio Graduate School of Media Design

1. I confirm that I have read and understand the purpose of the above research project and I have had the opportunity to ask questions about the project. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐

3. I understand that my responses will be kept strictly confidential. I give permission for the researcher to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. ☐

4. I understand that the data collected (including photo and video recordings) from me might be used in future research. ☐

5. I agree to take part in the above research project. ☐

____________________	____________________	____________________
Name of Participant	Date	Signature
____________________	____________________	____________________
Name of Researcher	Date	Signature

To be signed and dated in presence of the participant