SMOOTH
Reducing Hand Discomfort from Smartphone Overuse with a Control Ring

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Term Project: Report and Research Proposal

Abstract

From the researches we reviewed, our team realized that excessive smartphone use can lead to many health issues, including permanent injuries in users' hands and wrists, as well as cervical repositioning, and upper arm rheumatic pain. From children to seniors, everyone is affected by the inorganic size of the modern smartphone. The emerging issues caused by texting and tapping on smartphones is threatening the modern population's physical health. A user-centered product to help the users better enjoy using their smartphones appears to be valuable. By interviewing one heavy smartphone user to deeply understand her expectations, we realized that grasping a smartphone and scrolling up and down is the most common motion for her. Based on the interview insights, we narrowed down our objective to designing a small and lightweight device that would save people from grasping their smartphones by achieving the scrolling functions for them. After our team completed the final prototype, we found that our project has many potential health benefits, such as effectively reducing the risk of getting de Quervain's tenosynovitis. In addition, due to the human-centered design principle, our research area is expected to have great commercial value in high-tech companies.

I. Introduction

A. Background

Research has found that high levels of smartphone overuse consistently cause discomfort to users' wrists and fingers. One of the most common consequences of prolonged smartphone use is hand and wrist weakness [1]. This syndrome is caused by repetitive bending and straightening of fingers, thumb, and wrist. The worst consequence will lead to musculoskeletal disorders [1]. Especially contemporary teenagers have gradually become one of the leading groups affected by smartphone overuse. Smartphone use is founded to reduce hand and pinch grip strength and hand function in both dominant and non-dominant hands of children [2]. According to a study conducted to determine the relationship between the use of handheld devices and the prevalence of musculoskeletal disorders in the upper limbs, only a quarter of participants are known to be unaffected by hand pain symptoms. Of these, 44.5% were affected by mild hand pain, and 24% were affected by moderate hand pain [3]. Therefore, how to reduce the effects caused by the use of smartphones should receive more attention from society.

De Quervain's tenosynovitis is a syndrome caused by chronic overuse of the wrist, such as excessive texting on a patient's cell phone. The main symptom of this syndrome is sudden pain or tenderness at the MCP joint of the thumb. Sometimes, patients with de Quervain's tenosynovitis will experience pain extending into their forearm, which may develop slowly or suddenly. De Quervain's tenosynovitis occurs most frequently in women, with the presentation of pain and swelling in the first dorsal extensor sheath [4]. According to J.M.Wolf, there were approximately 11,332 cases of de Quervain's tenosynovitis in the population and 12,117,749 people are at risk of this conditon every year. Compared to Men, women had a significantly higher rate of de Quervain's tenosynovitis at 2.8 cases per 1000 person-years. [4]. With the development of the medical level, many treatments are available to reduce pain and swelling, including physical therapy (splinting, activity modification, modalities, manual treatment, and therapeutic exercise) and drug therapy (taking nonsteroidal anti-inflammatory drugs like ibuprofen and naproxen). Surgery will be discussed and performed if patients return with increasing pain and discomfort [4].

There is an existing device with a similar function to our project. It was a ring designed by the PADRONE company that can completely replicate the functions of a laptop mouse to reduce the damage caused by the long-term use of the mouse. This device is named "Padrone Ring," and the staff in PADRONE said, "there is no difference between using your laptop's touchpad and using the Padrone ring." This Padrone ring allows users to work like having an unlimited touchpad on the desk, even on any hard surfaces. The ring is able worn on the index finger, no matter on the left or right hand. Once the user's index finger touches the desktop, the ring will detect that motion and the mouse pointer follows the user's fingertips. When people lift their fingertips again, the mouse pointer stops moving. When users need to work on laptops, they can put their hands on the table in the same position and keep a relaxed posture for a long time.

B. Overview

Since de Quervain's tenosynovitis is mainly caused by chronic overuse, including repetitive movement and constant pressure on the thumb, we hypothesize that self-reported symptoms of de Quervain's tenosynovitis due to smartphone use, such as pain, swelling, and stiffness of the thumb and wrist, can be relieved by reducing the force applied on the thumb and the range of movement through a small, lightweight, and wearable smartphone controller. A 90-minute interview with a heavy cellphone user in *Section II* demonstrates the impact of cellphone usage on hand performance and the need to use handheld devices in a more relaxed way. On the basis of the interview, we proposed an assistive device in *Section III* to further address our hypothesis. By integrating gears into a ring to simulate the scrolling motion on the phone, we suppose that the device will help remotely control the phone rather than holding the phone in hand, which can effectively reduce the stress on fingers and wrist. If the hypothesis holds true, this research will impact studies and the development of assistive devices that aim to reduce the pressure on the hand by freeing the hand from holding the cellphone, as articulated in *Section IV*. Lastly, In *Section V*, we discussed how our findings could impact a broader range of applications since it has the potential to be adopted by high-tech companies to develop multifunctional devices that can fully replicate human hands to operate the smart device.

II. Preliminary results

To better understand user needs and expectations, we interviewed a high school student who self-reported to be a heavy user of the cellphone. The interview was conducted in person in a conversation format, in which the interviewee shared her daily activities, feelings, and habits of handheld device usage. From this 90-minute interview, we understood the interviewee's overall needs and how her expectations were related to her cellphone usage and behaviors.

First of all, the cellphone's screen time function suggested that the interviewee might have an average daily cellphone usage of 8 hours. Although she claimed that she never had any pain or discomfort on her thumb or wrist, the interviewee reported feeling pain on the thumb side of the wrist when performing the Finkelstein test, which might be a sign of de Quervain's tenosynovitis. Additionally, the interviewee was accustomed to holding her cellphone and other similar handheld devices with finger 5 (the little finger) placed underneath. As shown in Figure 1, a dent caused by resting the cellphone on the little finger was visible on the little finger, which was known as the "smartphone pinkie". Other than the deformation, the interviewee did not report any pain in the pinkie finger.

On the other hand, the interviewee's three most frequently used apps were TikTok, Instagram, and messages in order. In other words, scrolling up and down was the most commonly used gesture, followed by typing. The interviewee had tried some assistive devices, such as a smartphone stand and pop socket attached to the back of the cellphone to help grip. Still, none could effectively eliminate the stress on the thumb/wrist while allowing her to manipulate the phone freely. In addition, since the interviewee was a high school student on a tight budget, she showed a great preference for inexpensive products and did not care much about aesthetics.

Fig. 1: How the interviewee normally held the phone (left); visible dent on her little finger (right)

TABLE I: Key customer statements and needs

Customer Statement	**Customer Need**
High school student, uses cellphone after school	Inexpensive
Uses iPhone, iPad, and MacBook	Compatibility
Normally not charging while using	Battery life concern
Use one hand with pinkie finger underneath	Single hand use, comfortable for a long time
Prefers bigger phone	Can support heavier phone
No preference about phone brands	Compatible with all phone models
Bought my phone because it was cheap	Affordability
Uses TikTok the most/mostly scrolling	Replicate the scrolling motion

Overall, the interview was very informative and inspirational. We summarized the essential needs and expectations of the interviewee in Table 1. In short, the interviewee illuminated the need for a simple and affordable device to help handle the phone and reduce the risk of de Quervain's tenosynovitis. We believe that an assistive device that can reduce the force applied on the thumb and the range of movement will address some of her needs and help promote hand health.

III. Methods

Device Concept:

Our prototype was designed as a ring that the users can wear on their index finger. As illustrated in Figure 2, by rotating the gear on the ring with the thumb in the same hand, users can remotely control the smart device to scroll up or down.

As shown in Figure 3, the ring consists of an encoder, bevel gears, and a ring-shaped housing covering all the small components inside. Due to the tight time frame, our team decided to have a rough prototype with some components housed partially outside the ring case. For instance, the rotary encoder is too big to be fully enclosed within the ring's case. Therefore, we designed an open slot on the ring to fit the encoder, connecting to an external circuit board to communicate with Arduino. In addition, the team placed the big bevel gear, acting as a scrolling wheel, on the side close to the thumb to make it easier for the thumb to reach and rotate the gear. To improve our product's user experience and comfort level, the team aimed to make the wall of the ring thin enough to fit on the index finger without interfering with other fingers' motion.

Subsystems:

There are three subsystems for this design. Firstly is the wearable part (the ring shown in Figure 4). This part's main job is to take the motion of the user's thumb into a measurable signal and pass this signal into the microcontroller to process. The success of the wearable part was evaluated by (1) whether the up/down scrolling operation was smooth, (2) whether the gears could transmit finger motion to the

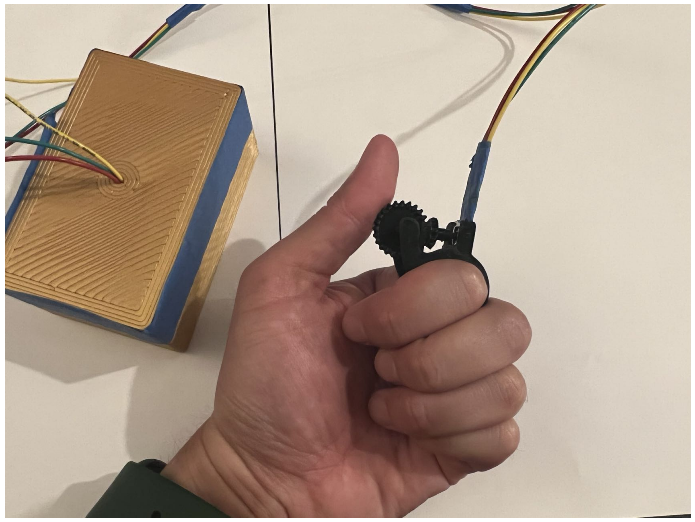

Fig. 2: Example of the use case

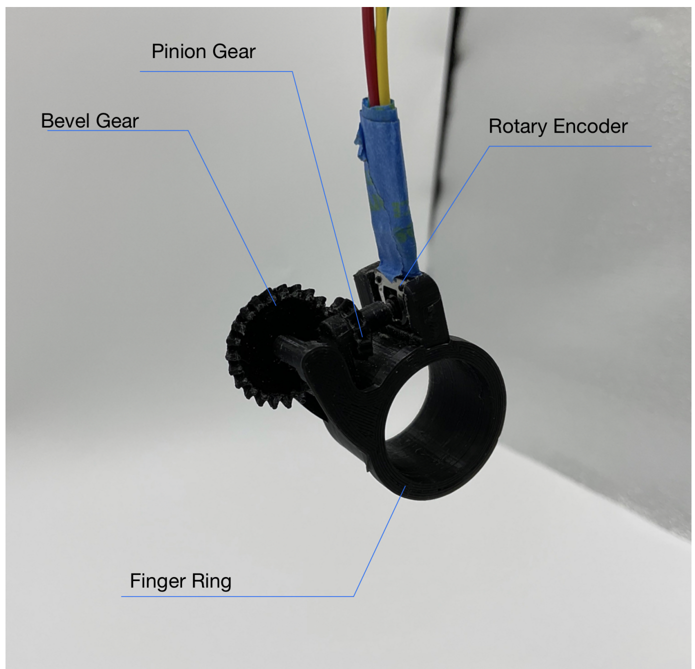

Fig. 3: Components of the ring

rotary encoder, (3) whether the encoder could convert the motion into the numerical signals and pass the signal to the next subsystem: the controlling box, and (4) whether the structure of the ring was robust and comfortable to wear.

Developing a circuit system from scratch was an unsurmountable challenge within this limited time frame. To deliver a functional prototype on time, the team had to compromise. Our group decided to have an Arduino microcontroller as the major circuit to process the signal from the rotary encoder and communicate with the smart devices through a built-in Bluetooth connection. One AA battery is connected to the ring with three wires to power the encoder. After the microcontroller processes the signal, it will communicate with the built-in Bluetooth module to command the phone to scroll up or down. The success of the controlling box was evaluated by (1) whether the microcontroller could interpret the encoder signal and process it fast and (2) whether the Bluetooth module could pass the command to the smart devices.

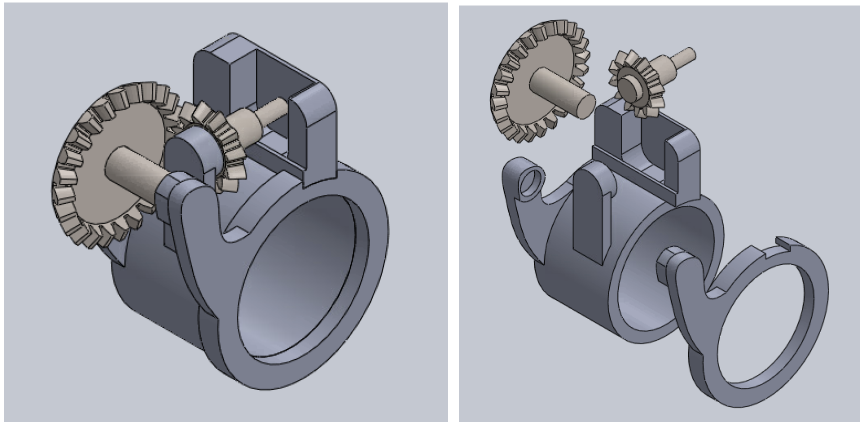

Fig. 4: CAD models of the ring

In addition to the ring itself, our team considered the whole using environment in our design. To further free the user's hand from holding the phone, we added a phone stand subsystem, shown in Figure 5, so that the user can place the phone on a table or lap.

Fig. 5: CAD models of the ring

Proposed Study:

To further assess the product, our team would like to select 20 people for this study: Group A contains ten people suffering from wrist pain, and Group B contains ten people who are free of any discomfort. All the people will be asked to use the prototype as much as they want to. After one week of testing, record any self-reported discomfort changes in Group A and Group B. This study investigates Group A participants with their wrist pain condition before and after using the product to see if the design addresses the problem. For Group B, we would like to see how likely people without wrist pain are willing to use our product before they have any wrist illness. Also, we would collect both groups' screen times to see the percentage of their overall screen time compared to the time they use this assistive device. Although the team has completed the CITI training, the study will only be executed with approval from the Internal Review Board.

Discussion of procedure/expectation:

The team will label all the testing devices with each tasting participant's name to make sure the data are well nominated and labeled. While the users operating the devices, the devices document the user

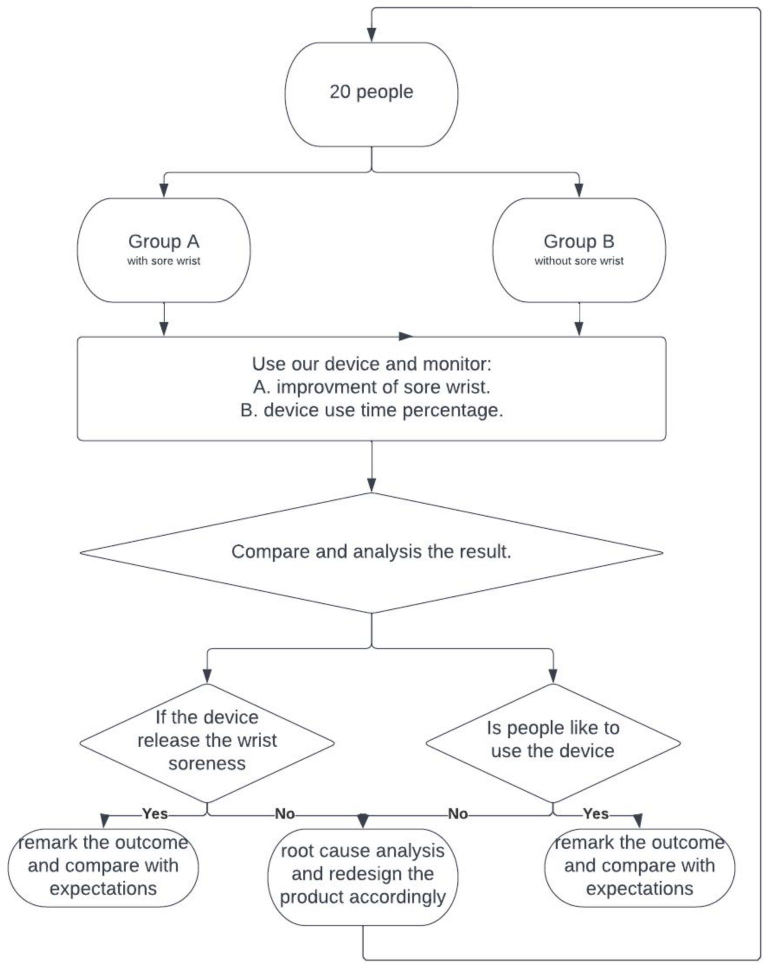

Fig. 6: State transition diagram

activity and how long/how many times each user uses the device every day. All the data will be collected together after the devices are returned back to the lab.

The expectation of the result is the use of the device can help the users reduce the hand/wrist discomfort by a noticeable change. Using the objective hand sore test and collect user's reflection from the simplified Patient Rated Wrist Evaluation (PRWE) questionnaire (shown in Figure 7), our team can measure how much our device can help improve the de Quervain's Tenosynovitis conditions. The Free response questionnaire (shown in Figure 8) helps the team understand how likely the user will use this device consistently. The outcome can reflect the positive influence on the sore wrist condition or affect the condition at all or make the discomfort even worse. By combining with the data stored in the device of the user using pattern and amount of time, the team will be able to tell the correlation between how the discomfort of the wrist with the device usage.

IV. Intellectual Merit

There are many potential benefits of this study. The industry can develop relevant products to eliminate the sour wrist condition. The phone designer can practice new designs on the phone. Moreover, the medical studies can use the data can the relation we studied to develop further studies. Although there is undoubtedly room for modification and improvement of this particular device, this study validates that de Quervain's tenosynovitis is caused by chronic overuse of the hand and is closely bonded with the amount

Rate the average amount of discomfort (including pain, soreness, stiffness, and inflexibility) in your thumb/wrist over the past week by circling the number that best describes your pain on a scale from 1-5. A one (1) means that you did not feel any discomfort and a five (5) means that you had the worst ever discomfort you have ever experienced					
Rate your pain:	1 No pain	2	3	4	5 Unbearable
At rest	1	2	3	4	5
When doing a task with a repeated movement	1	2	3	4	5
When lifting a heavy object	1	2	3	4	5
How often did you have discomfort	1 Never	2	3	4	5 Always
How the discomfort limited your performance	1	2	3	4	5

Fig. 7: Self-reported PRWE questionnaire

1. On a scale of 1-10 (1 being extremely uncomfortable, 10 being extremely comfortable), how comfortable was the ring? What made it comfortable/uncomfortable?

2. When/what app did you to use the ring with?

3. When/what app did you not use the ring with?

4. What did you like about the ring?

5. What did you not like about the ring?

6. Would you consider using the ring daily? Why/why not?

Fig. 8: Free response questionnaire

of force and range of movement of the thumb and wrist. This validation can motivate the academia to study further the causes, impacts, therapies, and factors related to de Quervain's tenosynovitis. Since we dug out user needs for an assistive device to address de Quervain's tenosynovitis caused by smartphone overuse, the industry can develop and market similar products on the basis of this study.

V. Broader Impact

This study illustrates the potential impact of smartphone overuse on human hand performance which may cause discomfort or pain in users' fingers and wrists and even lead to de Quervain's tenosynovitis. This symptom is caused by people holding their smartphones to texting or scrolling for a long time every day. In our project, a scroll ring is designed to replace the scrolling function of the smartphone, which can effectively reduce the time people hold their smart devices. Therefore, this product can help users liberate their hands from grasping the phone, which can significantly reduce the impact of the phone on the fingers and wrists. It is not only suitable for people who are already diagnosed with de Quervain's tenosynovitis, but also for healthy people who operate their smartphones for a long time to help prevent the potential impacts and risks of excessive grasping of smartphones. Since the concept of our project is to design a ring that can replicate the users' scrolling motion of the thumb to control the smart device, it has the potential to be adopted by high-tech companies to develop multifunctional devices that can fully replicate the functions of human hands. Overall, our project is the beginning of the smartphone remote control field. There will be more exploration and investment in the future to develop better products for people to remotely operate their smart devices.

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Appendix A
Discovery Decomposition

Topic of the interview: daily usage of hand held device and hand performance.

1) Effect of Smartphone on Hand Performance and Strength in the Healthy Population: [1]
This paper shows that one of the most common consequences associated with increased smartphone use is hand and wrist weakness. This condition is caused by repeated flexion and extension of the fingers, thumb, and wrist, leading to musculoskeletal disorders. The author investigated 1005 healthy volunteers and assessed their grip strength in an attempt to find an association between smartphone usage duration and hand-grip strength. As a result, a non-significant positive association was found between smartphone addiction and upper extremity dysfunction.

2) Evaluating hand performance and strength in children with high rates of smartphone usage: an observational study: [2]
This paper presents a study of the effects of smartphone use and hand dominance on children's grip strength, pinch strength, and functional hand performance. And the author shows the conclusion that high-level smartphone use was found to reduce hand and pinch grip strength and hand function. However, hand functions were affected in both the dominant and non-dominant hands with either high or low-level smartphone use.

3) An extensive usage of hand held devices will lead to musculoskeletal disorder of upper extremity among student in AMU: A survey method: [3]
This paper describes a study conducted to determine the relationship between the use of handheld devices and the prevalence of musculoskeletal disorders in the upper limbs among AMU students. Only a quarter of participants are known to be unaffected by hand pain symptoms. Of these, 44.5% were affected by mild hand pain, and 24% were affected by moderate hand pain. The authors found that prolonged cell phone use is known to cause symptoms of musculoskeletal disorders and suggested doing more studies in the future to create awareness among cell phone users.

4) Tenosynovitis Caused by Texting: An Emerging Disease: [5]
This article presents a real case study of bilateral de Quervain's tenosynovitis (which is often associated with rheumatoid arthritis and pregnancy) caused by excessive texting on a patient's mobile phone. The author introduced the causes, diagnosis, and treatment of this tenosynovitis in detail, including naproxen, cock-up wrist splints, and limitation of texting, which resulted in the complete recovery of the patient. This case made doctors aware of a possible link between tenosynovitis symptoms and excessive texting.

5) Grasp and index finger reach zone during one-handed smartphone rear interaction: effects of task type, phone width and hand length: [6]
This paper introduced a recent study, which investigated the effects of task type, phone width, and hand length on grasp due to the fact that, recently, some smartphones have introduced index finger interaction functions on the rear surface. The author considered five interaction tasks, two device widths, and three hand lengths, and the study results showed that the rear interaction regions of five commercialized smartphones should be lowered by 20–30 mm to reach the most comfort gesture.

6) Influence of hand and smartphone anthropometric measurements on hand pain and discomfort: [7]
The purpose of the study is to investigate the relationship between smartphone and hand anthropometry measurements and handgrip strength. This research recruited 89 university students from age 17 to 30 who use touch screens regularly, of them have experience with hand pain. Researchers divided the students and phone models into 3 groups respectively based on their hand sizes screen sizes and measured their

handgrip strength using a hydraulic hand dynamometer. In conclusion, there was a tendency to use small mobile sizes while the majority had medium hand sizes, which is in line with the reduced hand pain. This suggests customers match hand size to the smartphone size to reduce musculoskeletal disorders.

7) The association between smartphone addiction and thumb/wrist pain: [8]
This research is to investigate whether smartphone users' pain in the thumb/wrist is related to their addiction to smartphones. A total of 387 medical students were recruited and divided into 2 groups: the smartphone addict group and the non-addict group. Pain in the wrist/hand was also evaluated using a self-reported questionnaire and the Finkelstein test. In conclusion, the study found a significant correlation between smartphone addiction and thumb/wrist pain. Mobile texting is the biggest risk factor for De Quervain tenosynovitis in the thumb.

8) Frequency of thumb pain among mobile phone user students: [9]
This study enrolled 110 students from 18 to 25 years old to evaluate the relationship between the frequency of thumb pain and mobile phone usage. Results showed that 40% of participants experienced pain in the thumb while 41% of the respondents reported the duration of phone usage to be 5-7 hours daily, which are in line with the research conducted by Maryam Ali.

9) Musculoskeletal Disorders of the Upper Extremities Due to Extensive Usage of Hand Held Devices: [10]
This study is to describe the risk factors and clinical features of the musculoskeletal disorders associated with the usage of handheld devices (such as mobile phones, game controls, and tablets). 70 subjects reported pain or stiffness in the thumb/wrist mostly of their dominant hand since most activities promoted the predominant usage of the thumb or only one finger. 33 subjects reported onset of symptoms following extensive text messaging. Size of the screen, static loading, and duration of holding were dominant factors that related to the pain.

10) Statistical study on the effect of the use of mobile phone technology on human body health: [11]
This study is to investigate the relationship between the number of hours of use of mobile phones, the pain in the head/hand, and the thermal effect in the head/hand (due to radiation exposure) when the phones are in idle and dedicated mode. Results showed a strong correlation between the duration of phone use and the pain in the head/thermal effect on the hand, which means that there is a relationship between phone use and the effects in human body health during the dedicated mode.

11) Risk factors and clinical features of text message injuries: [12]
In this paper the author elaborates on all the possible illnesses caused by the extensive texting on mobile devices. The author not only show the possible victims of those illness but also shows the types of the smart phones that are involved in this study. By deeper look into the illness terms we can seek for anatomy illustration for next step study.

12) The Comparison of Cervical Repositioning Errors According to Smartphone Addiction Grades: [13]
In the article the author illustrates the study of how the addiction of smartphones influences cervical repositioning. He believes this issue can be solved through social recognition and intervention. But from this paper we see that the position correction is the key or the direct solution of this problem. By referencing this paper, not only hand pain as a result of smartphone overuse but also the cervical repositioning. Our prototype can have this issue in mind while developing. There is a chance we can have both pain points solved together.

13) Musculoskeletal pain and musculoskeletal syndromes in adolescents are related to electronic devices: [14]
In this article, author articulate the relations between musculoskeletal pain and syndromes with the use of electronic devices, especially in the adolescents population. The research has collected 299 healthy adolescents from a private school. All students are asked to fill out questionnaires. However, they are not only asked about their daily use of their phone but also regards the other electronic devices for example computers, electronic games, and etc. the result shows that more than half of the students had experienced musculoskeletal pain syndrome (61%), which is noticeably much higher compares with those without this condition. This study shows the necessity of attention to care about the usage of electronic can bring pain in the adolescent population.

14) [Video]Muscle of the hand - Anatomy Tutorial.: [15]
In this Video tutorial we learnt the hand muscle anatomy especially for the muscles used for the thumb. The tutorial highlights the muscle structure that supports thumb movement and how the hand shape influences or supports the movement of the hands. The hands anatomy also shows how the muscle directions enable the hand movement directions. With the structure of the hand clear in our mind, we can have a better understanding of how to design our product to fit the user's hands better.

15) Is smartphone addiction really an addiction?: [16]
The cause of hand pain from the addiction of the smartphone is one of our main study subjects. To truly understand and help our user to deal with their hand pain, we need to understand the root causes. In this article Arthur offered an innovative angle of seeing addiction to the smartphone. He described addiction as a disorder with severe effects on physical and psychological health. In our case, we would concentrate more on the physical effects for our study. However, the author rather concentrated on the psychological effect instead of the physical effect.

APPENDIX B
INVESTIGATIONAL DEVICE DETAILS

Rotary encoder:

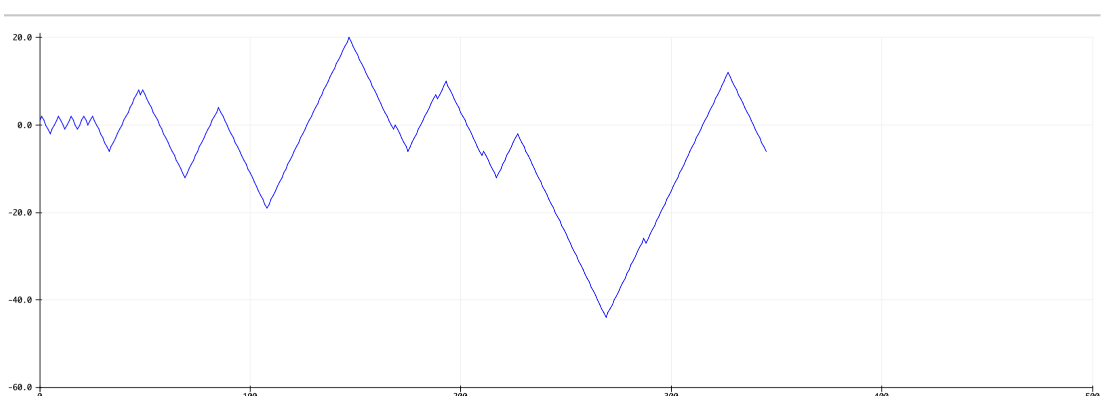


Fig. 9: Arduino plot of the endless rotation of the encoder

Brainstorming and decision making:

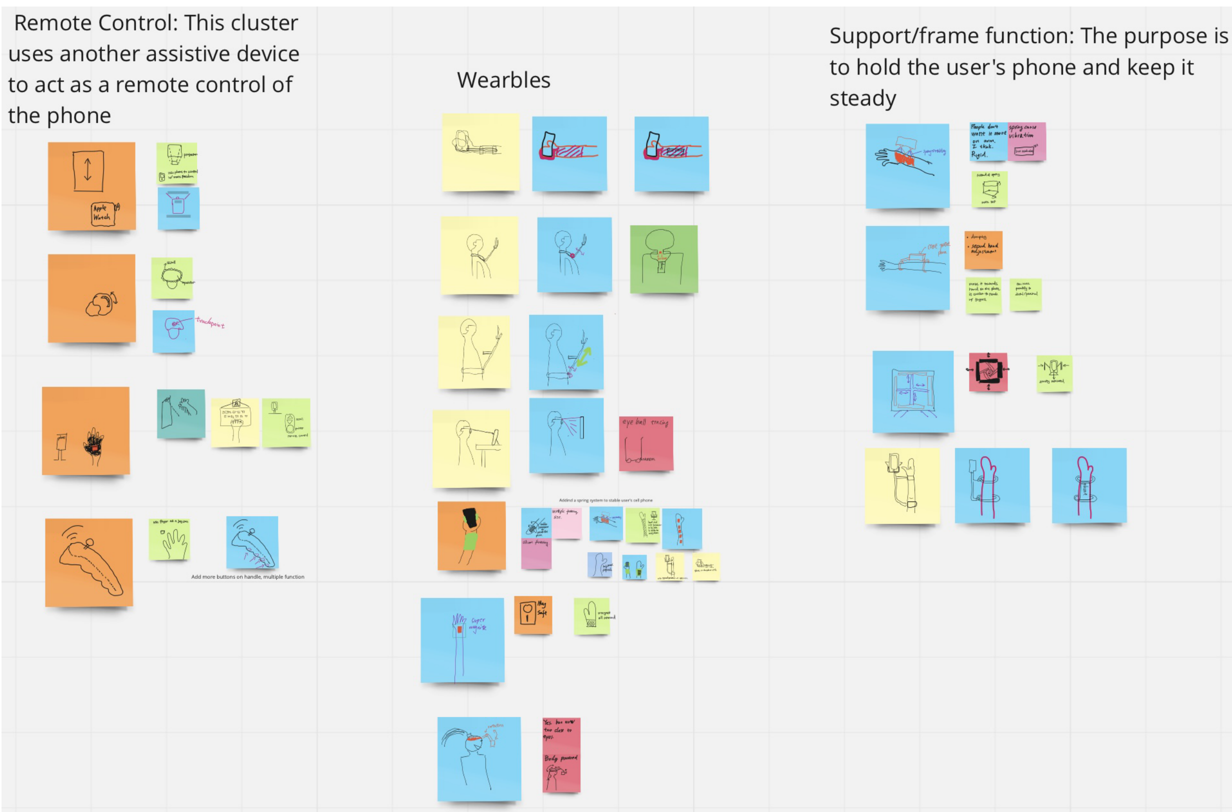


Fig. 10: Brainstorming ideas

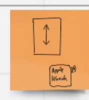
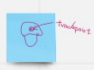
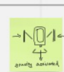
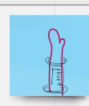
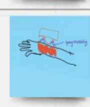
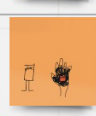
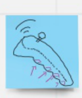
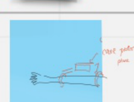
solution		simplicity/easy to use	address the problem	comfort	release body from any pressure	durability
1		4+5+3	2+2+2	4+4+3	2+1+3	4+5+5
2		4+4+3	5+3+3	2+2+2	1+1+1	3+3+3
3		2+2+3	1+0+2	3+4+3	5+4+3	2+0+1
4		2+2+2	4+4+3	5+2+2	4+5+3	1+3+2
5		4+4+3	2+4+2	3+2+3	2+2+2	5+3+4
6		3+5+4	2+0+2	3+2+3	0+2+1	5+5+5
7		3+2+4	4+0+2	3+1+2	4+3+2	3+2+1
8		2+4+5	3+4+5	2+3+3	2+4+5	2+3+5
9		4+3+4	4+5+5	5+5+5	5+5+5	3+2+5
10		3+3+2	3+2+1	2+1+1	4+3+1	2+5+5
11		3+2+3	3+2+2	3+1+3	4+2+2	3+4+5
12		3+4+1	4+3+2	2+3+2	4+2+3	3+2+1
13		2+2+5	3+4+5	3+4+3	4+5+3	2+2+5
14		3+4+4	4+4+4	3+5+4	2+5+3	2+5+2
15		3+3+2	3+3+2	3+2+2	3+2+2	2+3+3

Fig. 11: Decision matrix and solution assessment