Supernumerary Enhancement For Hemiparesis

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Augmenting Human Dexterity – Spring 2021
Term Project Report

Abstract

In this report we propose a supernumerary prosthetic device to act as a testbed for identifying the relationship between mental fatigue and device engagement for patients with hemiparesis. After performing a review of the current state of prosthetic devices for hemiparesis, and conducting an interview with an actual patient suffering from this condition, we have identified an issue that has not always been at the forefront of prosthetic design: the mental fatigue generated through prolonged use of assistive devices both for mobility enhancement and therapy. In our proposed 6-week study, we seek to prove this relationship through qualitative analysis of patient's interactions with our proposed device in their daily living. If successful, we discuss the possible benefits of our findings, both for the intellectual community and the hemiparetic community, in the development of new frameworks for prosthetic design.

I. Introduction

Hemiplegia, or hemiparesis, is a common post-stroke condition that reduces the dexterous manipulation of affected patients. It can take the form of partial or complete paralysis developing in the fingers and, depending on the severity of the case, even propagating through the entire arm. [1] Roughly 66 to 71 million adults over 20 years old suffer from post-stroke hemiplegia every year. [2] [3] For patients suffering from this condition, redeveloping their motor control and dexterity through physical therapy, or, learning to live with an assistive device, is their top priority. Patients usually start with physical therapy, and when they plateau, they start using an assistive device. [4] These devices can take forms ranging from a simple support strap, to assistive grippers, to fully actuated prostheses–all depending on the severity of the case. They seek to enhance the user's lost motor function but may also have secondary goals like accessibility and comfort. By focusing on both improving the user's dexterous manipulation and the user's conformity with the device, we aim to get the user to use the device more often, and gradually wean them off their need for the device through the device's intrinsic therapeutic properties.

A. Background

In order to better understand the scope of hemiplegic therapeutics, a literature search was conducted to learn how to quantify, rehabilitate, and assist stroke patients with the condition.

Multiple post-stroke side effects are diagnosed through standard dexterity tests, like the Nine Hole Peg Test and Modified Ashworth Scale. These quantify and identify symptoms like apraxia, visuospatial problems, speed, coordination, and more. [5] However, since 1999, researchers concluded that the diagnosis of brain damage and spasticity from stroke had such unreliable clinician diagnoses that these tests can not accurately quantify all stroke patient symptoms. [1] [6] As a way to mitigate this case-by-case basis, our project focuses on a single stroke patient with hemiplegia, and her specific problems, which tailors our device to their specific needs. However, with all considerations in mind, our interviewee may still have other implicit needs not addressed in past papers; this is due to previous literature already generalizing the needs of individual patients. Therefore, we need to tread carefully as we uncover our specific interviewee's needs, especially regarding rehabilitation.

To do this, we analyzed various therapeutic findings to assist hand impairment. Dexterity was shown to have drastically decreased after quantifying the dexterous force of stroke patients. [7] However, electromyography (EMG) data of hand muscles brought more recent findings on how to mitigate these post-stroke issues. [8] An initial study found that muscle length only affects strength, and not dexterity. This brought about a recommendation to use therapeutic devices that encourage hand-stretching, extension, and flexion in order to reduce chronic spasticity - a symptom that our specific individual also suffered from having. [9] Moreover, the use of vibrational tactile feedback also increased dexterity and speed for patients. [4] However, an issue we found in this therapeutic device framework was the continual usage of body-powered, bulky equipment. [10] [11]

To form the basis of our designs, we also looked to specific examples of past assistive devices. These include passive devices, exoskeletons that assist in bimanual tasks, graspers, pinchers, and more. [12] A popular design, the handSOME device, is a passive pincher that changes the tension force for grasping objects, which could be adjusted as the user regains motor function. [13] A 2012 design by Chiri et al. under-actuates individual fingers to allow greater motion at the cost of being a compact and lightweight attachment. [14] Supernumerary devices like the Ort hand remove control from the hand in favor of controlling bulky external fingers that allow for gross motor control and usage of the arm. [15]

Altogether, these devices work well for their intended uses, but they also generate some flaws: While case-dependent, Lum et al.'s 2012 framework for devices created labels of "endpoint control", "fixed ratio", "actuated object", and "exoskeletons", which we believe unintentionally limits and isolates these assistive technologies. [16] The handSOME laid the groundwork for many future devices, but we found that it required immense initial mental effort to manipulate an affected hand, and that this strain was not taken into account. The Chiri and Ort devices were more akin to bulkier exoskeleton prostheses, and left a huge gap for low-profile and lightweight prosthetics. We were able to find equipment with much smaller device footprints, but these had cumbersome control methods that ranged from an EEG-embedded baseball cap to wireless mimicry of an exoskeleton on the functional opposite hand. [17]

These methods do not address everyday tasks of the user, and create gaps in our contextualization of therapeutic devices. While our device also aims to provide rehabilitation, we determined that these previous bulky devices were very explicit and required active attention and focus; there was little consideration for the mental fatigue that these devices bring, yet our interviewed person continually mentioned how strenuous therapy was. Therefore, we intend to address the usage of passive, low-stress rehabilitation that still incorporates aspects of past assistive technologies.

B. Overview

In order for a patient to gain the therapeutic properties of an assistive device, they must first be willing wear and use the device for long periods of time. Recognizing that there are inherent challenges with this caused from mental fatigue induced from the prolonged use of a prosthetic, we draw the following hypothesis: **that a low-profile and lightweight gripping therapeutic will increase our user's accessibility, acceptability, and engagement with the device, due to a lower amount of mental fatigue associated with such a design.** As discovered from our preliminary interview with a hemiparesis patient, discussed in Section II, mental fatigue not only can discourage the use of a prosthetic device, but also the willingness to go to occupational therapy. As such, in Section III, we propose a lightweight supernumerary device that will enable us to study the relationship between mental fatigue and a patient's emotional and physical relationship with a device. This will be categorized by their acceptability and engagement with the device in a study that is also proposed in Section III. If our hypothesis holds, we could encourage new frameworks in prosthetic design as discussed in Sections IV and V.

II. Preliminary Results and Motivation

Broadly, the interviewee is a 21 year old female that suffered a stroke the age of 16. She developed symptoms of hemiplegia post-stroke, and thus has weakened mobility in her right arm, and handles most tasks with her left. For several months the stroke patient went to occupational therapy and was able to regain some mobility; however, it was a highly time-consuming process and the certainty of healing was unclear. This therapy was affecting her school and work, so she stopped going to live a more normal life.

Throughout our interview we leveraged contextual inquiry, using a loosely structured set of questions and then letting her guide us through her various experiences with hemiplegia. Much of the interview was grounded in her daily activities, ranging from tasks she can no longer do, tasks she's adapted to, and tasks she still does well. She expressed extra difficulty with picking things up which informed a lot of our need finding hierarchy and eventually our design decisions.

Of all the data we collected on our interviewee, we ended up converging on a few main insights regarding her ability to grip and hold things. In one case regarding arm use she recounts, "anything involving my arm takes a lot of emotional energy [...] I have to be in a good place mentally just because [...] It's so annoying [...] because of that, you don't want to use as it much and then [...] it doesn't improve with use. It's [...] a vicious cycle." Taking this information into account, we made it a point to design something that isn't cumbersome, that aids in arm mobility and could even provide passive therapy, and that increases dexterity in a way that improves the versatility of her current mobility. Some of the tasks included in these design considerations came straight from the interview. For example, she has issues strumming a guitar, zipping up her dresses, squeezing toothpaste, holding her iPhone, doing her hair, and spreading cream cheese on bagels. (see Appendix C for more interview preparation and complete user needs)

Most poignantly, our interviewee uses her paralyzed arm as a stabilizing arm, and expressed the most frustration with gripping items or holding them down. In response to this, our team came up with a soft gripper system that is able to expand enough to pick up items with a circumference similar to a large water bottle, or collapse down enough to hold a smartphone or a device handle. In line with these design decisions were the primary needs established in our user needs chart, the top 5 needs are as follows, in order of most to least important:

1) **The product isn't annoying or cumbersome to use**;
   - The product is a muscle stimulation/therapy device that the user can forget about, yet it still does its job consistently.
   - The product is easy to use and does not fatigue the user.
2) **The product increases finger dexterity**;
   - The product has fine manipulation to handle pinchable objects.
   - The product can isolate objects to make them easier to interact with.
3) **The product aids and improves arm mobility**;
   - The product is able to complement existing adaptations for arm movements and dexterity.
4) **The product is functional in a variety of situations**;
   - The product must be able to support objects when lifting.
5) **The product is easily accessible**.
   - The product can secure objects in place and is relatively low profile.

III. Methods

A. Device Overview

When designing our device, we drew heavily upon previous supernumerary devices like the designs of Ort et al. [15] and Hussain et al. [17]. However, whereas these devices were actuated by an outside source, like mirroring the user's functional hand, our supernumerary device is actuated by sensing muscle contractions in the user's forearm. By measuring the contractions generated from the user's wrist flexion, we can actuate a set of supernumerary grippers located on the palmar side of the wrist. Likewise, when the user extends their wrist, the grippers open up.

Our goal is to use this coupling of motion to allow the patient to improve their grip strength by having additional fingers for stabilizing and grasping objects. For example, a user could attempt to grab the lid of a jar of peanut butter, but lack the grip strength to both twist the lid and stabilize the jar. With this device, they could use whatever wrist strength they have to stabilize the jar and then use the grippers to

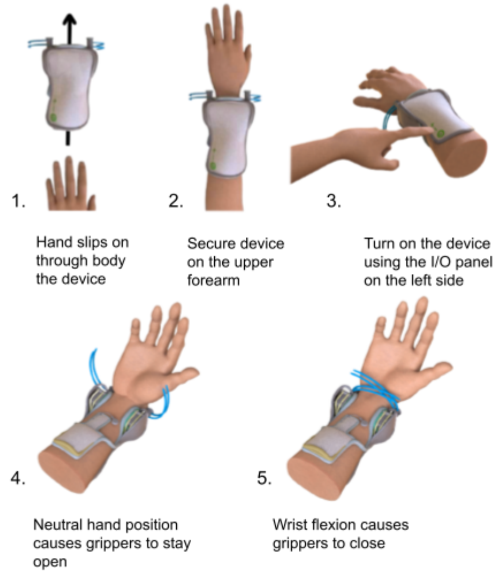

Fig. 1. Storyboard of donning and doffing device with visualizes for actuating the device.

firmly grasp and twist off the lid with the rest of their arm. Due to the versatility of this device, users can come up with their own ways to approach tasks and solve problems unique to them. Moreover, this device could be described as a passive therapeutic since it slowly retrains the user's brain to associate certain muscle contractions with gripping motions as they use it.

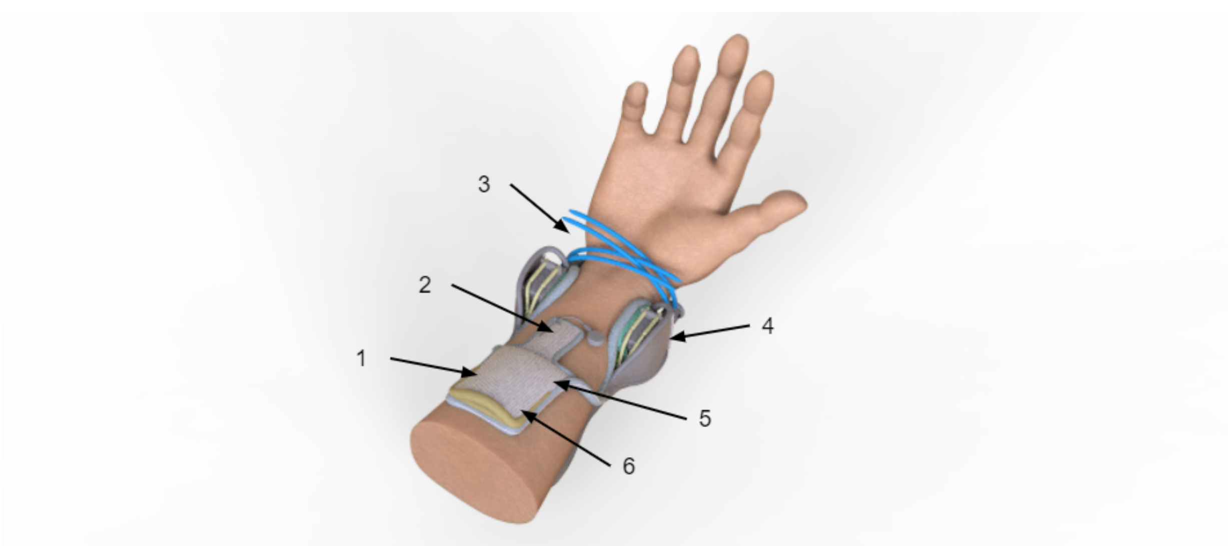

Fig. 2. An overview of the components that make up our proposed device: (1) Arm strap to hold device in place made from breathable mesh and lycra, (2) Myoware EMG Sensor, (3) EPU 40 grippers with reinforced fiberglass resin core, (4) High torque–low voltage and weight servos, (5) ESP32 Microcontroller (Hidden), (6) Rechargeable lithium-ion battery (hidden).

When selecting each part to use, we prioritized small form factor and tried to minimize complexity. This is not only for ease of manufacturability, but also keeps the device low-profile and allows the user to not be overburdened. (see Appendix A for more details)

B. *Testing Procedure*

To test the effectiveness of the device, we propose a multi-stage study to be performed over the course of 6 weeks. This qualitative study will assess the user's acceptability and engagement with the device by analyzing their opinion towards and interaction with it. Participants would be given a device to use in their daily life at home. At the end of the study, participants would be interviewed and asked to fill out a survey based on their experience. The results of this study will be inherently subjective since each patient would be asked to give their own personal opinion of their interaction with the device. Although this leads to challenges with generating quantitative data, the qualitative data collected from this study will help us understand an individual's emotional and mental responses to the device. From this, we hope to gauge a greater sense of the challenges (both mental and physical) that having an assistive device poses and encourage designs that reduce these effects.

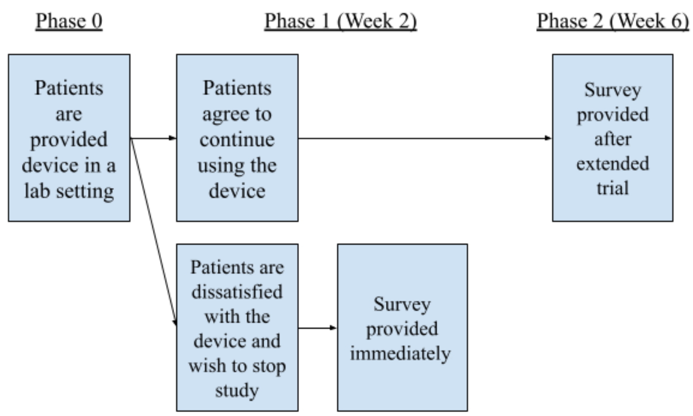

Fig. 3. Timeline of proposed study.

Our testing population would consist of patients with mild to moderate hemiparesis. It is a requirement that patients have some wrist mobility since it is integral to the actuation of our design. For phase 0, patients will be presented the device in a laboratory setting where they will become acquainted with the device. The device will be calibrated to their specific muscle contractions and arm shape for sensing and comfort. This would be done through a rudimentary test of the user opening a jar with a twist-off lid. Once they are comfortable with using the device on their own, patients will bring the device home and be encouraged to use it in their daily life (phase 1). After two weeks, the patients will return for a follow-up appointment where we would work out any other issues with the device that may not have arisen during initial testing. If patients are comfortable with the device and have no hesitations, they will be encouraged to continue using the device in their daily life for additional 4 weeks (phase 2). Otherwise, they would be asked to fill out a survey. The same survey will be given to participants that continued with the study at the end of their extended session.

We expect that those who took the survey after 2 weeks of using the device would not have had as good of an experience with the device than those who were comfortable with using the device for longer. As such, we will holistically use the data from phase 1 to identify sources of poor experiences for users and the data from phase 2 to identify things that worked well for certain users. A deeper discussion of how this survey was developed can be found in Appendix B. However, we are confident that the results of this survey and study will allow us to identify a correlation between mental fatigue and a user's accessibility and engagement with the device.

IV. Intellectual Merit

A common trend that proof-of-concept assistive devices have is that they do not particularly emphasize the psychological impact that these devices have; among the many issues we have identified from our

Background, the largest unmet need from previous studies is the mental strain accumulated from these devices. The prototypes from our literature review are inherently bulky and cumbersome, which adds stress to the user. In contrast, our design is meant to provide a low-profile design while doubling a passive therapeutic for rehabilitation. It is a device intended for usage in a home environment that is comfortable to wear for extended periods of time, even if it is not the perfect supernumerary device. We seek to use our findings to provide a framework for the next generation of assistive devices that addresses the mental fatigue of rehabilitative devices and allows for further research regarding comfort after extended use periods.

V. Broader Impact

By performing this research, we hope to find a link between mental fatigue and the user's acceptability and engagement with the device. From this, we hope to start the necessary development for a framework that guides the design of devices around these topics. That being, lightweight, intuitive, and effective prosthetic devices. The end goal being that patients will be more likely to use their devices. Recognizing that a device's use is not only for mobility enhancement, but also a passive therapeutic, the next logical step is to have a user so encouraged to use a device, that they may, one day, no longer need the device. Although lofty, if this attitude can be applied to the design of prosthetic devices, we can develop technologies that will continue to permanently heal users that have otherwise considered themselves at a plateau in the road to recovery.

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APPENDIX A
INVESTIGATIONAL DEVICE DETAILS

Fig. 4. Early Iterations of Gripper Geometry

As shown above in Fig. 4, there were many design iterations that went into developing our investigational device. The way it functions is simple: Data collected from our EMG device (Myoware EMG) is eventually sent to our micro-controller (a Huzzah Feather ESP32), where it generates PWM commands for our servos (Standard Size High Torque Servos from Adafruit). All sensors, motors, and controllers are held in place by a comfortable, breathable strap which also holds a rechargeable lithium-ion battery that powers all these devices. Pseudo-code for the actuation of the servos driven by the EMG data can be found in Fig. 5. We implemented a quasi-hysteresis model of using a lower and upper threshold by recording the prior recorded force. This would allow processing and fine-tuning of the noisy EMG signal, which would be variable depending on the

```
void projectGripper() (
      // Measure the difference between EMG values
      long EMG_val = 0
      long prev_val = EMG_val
      if EMG_val > threshold then(
            // Measure the difference in force readings between the
               current reading and the previous reading
            if the force difference is greater than our threshold then:
                  //activate gripper motor
            else
                  //deactivate gripper motor
            update time value
            update force value
      )
)
```

Fig. 5. Preliminary pseudocode based on Arduino language

It is important that the strap held down the EMG firmly to the skin to ensure good signals are sensed. As such, our initial interactions with the patient in the lab setting are essential. Not only do we need to edit the hysteresis of our code depending on each patient's EMG response. We would also need to ensure the device is adjusted to the user's arm geometry to reduce noise in the system and ensure good contact with the EMG. This is done by physically adjusting the Myoware sensor with a screwdriver and the position of the sensor with the adjustable straps to ensure the correct voltage reading. The issue of hysteresis or signal saturation occurring beyond our initial calibration lead us to design additional buttons for the user to adjust the gripper's response on the fly. From this, they can ensure that the correct amount of force actuates the grippers when the user desires it.

Another great development we had was creating the design of the grippers offset from each other. From this we are able to have the grippers fold into themselves as they close. As such, when the device is turned off, it becomes nothing more than an extravagant bracelet for the user - hopefully adding to the acceptability of the device in the user's everyday life.

APPENDIX B
ACCESSIBILITY, ENGAGEMENT, AND MENTAL FATIGUE SURVEY

The following is an example survey that would be given to patients who would be participating in our study–pending approval. The bolded titles identify the various sections of the survey for the reader's reference. The survey handed to patients would be only questions.

The questions for this survey were developed from common concerns that were brought up during our preliminary work with our interviewee. The Mental Fatigue Scale (MFS), developed by Johansson et al. [18] [19] (which in itself is a derivative of the Comprehensive Psychopathological Rating Scale (CPRS)), was used as a stepping stone in designing the format of the survey and expected responses. A combination of multiple choice and free responses questions are used to gauge the level at which, and the reasons behind, a user having accessibility, engagement, and mental fatigue issues with the device. With each multiple choice question being rated out of 4 and a higher score being correlated with accessibility, engagement, and mental fatigue problems.

Accessibility

How easy is it for you to put on the device?

1) It is very easy to put on the device.
2) There are some issues with putting on the device, but I can overcome them by myself.
3) There are many issues with the device and I require outside assistance to put it on.
4) It takes significant time and effort to put on the device to where it is not worth wearing.

When wearing the device, how comfortable is it? This can be relating to the weight, feel, or look of the device.

1) The device is very comfortable, it does not weigh me down much, and I feel good when wearing it.
2) The device is somewhat comfortable, there are times when it gets in the way, is too heavy for me, or is too hot, itchy, sweaty, etc...
3) The device is uncomfortable to wear but I can overcome its flaws and still wear/use it.
4) The device is unbearable and it takes great effort to wear it.

If you had any issues with wearing the device, explain in your own words what they were:

How easy is it for you to take off the device?

1) It is very easy to take off the device.
2) There are some issues with taking off the device, but I can overcome them by myself.
3) There are many issues with taking off the device and I require outside assistance to take it off.
4) It takes significant time and effort to take off the device to where it is not worth wearing.

Engagement

How taxing is it to use the device?

1) The device is easy to use and I don't have issues in operating the device.

2) It takes some effort to use the device, but I feel with practice I will adapt to it more.
3) I am straining to use the device, but I can still accomplish tasks.
4) It takes significant effort to use the device and I don't see a way to overcome the challenges paired with the device.

How often do you use the device?

1) I wear the device all the time and only take it off when needed (sleeping, showering, etc..).
2) I use the device frequently, almost everyday.
3) I use the device occasionally, a few times a week.
4) I use the device less than once a week.

How much does the device assist you in everyday tasks? (Opening jars, carrying objects, lifting objects, etc. . .)

1) The device helps me accomplish everyday tasks frequently.
2) The device is helpful in completing some everyday tasks, but not so much in others.
3) The device is helpful in some specific everyday tasks but is not helpful for most tasks.
4) The device does not help me with any of my everyday tasks.

How much does the device assist you in complex tasks? (Tying hair, manipulating irregular objects, playing instruments, etc..)

1) The device helps me accomplish complex tasks frequently.
2) The device is helpful in completing some complex tasks, but not so much in others.
3) The device is helpful in some specific complex tasks but is not helpful for most tasks.
4) The device does not help me with any complex tasks.

If possible, in your own words explain a time when the device helped you with a normal living task that you normally would have struggled or not been able to do:

If possible, in your own words explain a time when the device hindered your ability to complete a normal living task and you would have been better off not using it at all:

What are your feelings toward the device? This could be in reference to how you feel the device looks on you or how it makes you feel.

1) I feel confident when wearing the device and it is an extension of myself.
2) I feel good when wearing the device but it is just a tool to help me.
3) When wearing the device, I view it as a crutch that I must use to complete my goals.
4) I am ashamed, embarrassed, or have other strong negative feelings when using the device.

Fatigue

After using the device have you felt fatigued at all? It does not matter if the fatigue is physical (muscular) or mental.

1) I do not feel fatigued at all.
2) I feel fatigued sometimes when using the device, but I can use it again after some rest.
3) I feel fatigued often when using the device and resting doesn't help much.
4) I feel fatigued all the time when using the device and taking a rest makes no difference.

How long do you need to recover after using the device for extended periods?

1) I need to rest for less than an hour before continuing to use the device.
2) I need to rest for more than an hour but feel refreshed and ready to continue using the device.
3) I need a night's sleep before I can continue using the device.
4) I need several days of rest in order to recover after using the device.

How much stress does the device induce when you interact with it?

1) I am able to cope with any problems the device provides in a usual manner.

2) I am stressed by the device, but only in demanding situations where the device is not performing as expected.
3) The device stresses me easily. I feel stressed when using the device in situations that previously did not bother me.
4) The device is very stressful to use and I rather not be burdened with it.

Appendix C
Interview Documentation

A. Interview Preparation

1) Write your own list of the elements that you will address with the interviewee at the beginning.:

- How are you today?
- Let's do a round of introductions. I'll go first.
- Tell me about yourself?
- This is a safe space, and we have no judgement on what you say.
- Just tell us if we ask anything that is too much - you only need to answer what you feel comfortable with.
- You can stop the interview at any time.
- As a confirmation, you're okay with us recording this, right? Again, all this data will be confidential, and we'll delete it at the end of the semester.
- As a refresher, the purpose of our project is to address human dexterity and mobility. With that framing this interview, we wanted to specifically ask you about your experiences in (living with a stroke).
- You're okay with this interview being around an hour in length, right?

2) Report your list of topics and questions (at least 10).:

- When was the last time you've went felt frustrated on performing daily tasks?
- How have you adapted since your stroke?
- What distinct differences in your actions have you noticed from before your stroke?
- What is the most frustrating aspect of your day-to-day life?
- Walk me through your morning ritual. How do you prepare for a typical day?
- How do you typically go about performing (task)?
- What was your recovery process like?
- Was there anything you did to help bring control back to your arm?
- What's one thing you get annoyed with that wasn't too tedious before, and that you do differently?
- How does living with hemiplegia make you *feel?*
- If I were a newly recovering stroke patient, what would be the best advice you could give to me?

3) Write out the list of important points for your team for concluding.:

- Thank you so much again for taking the time out of your day to have an interview with us!
- Again, this recording and data will be kept confidential and deleted at the end of the semester.
- We're going to convene as a team and discuss the needfinding insights, but we already are confident that you've given us a lot of great leads.
- If It's okay with you, we might be reaching back out to fill any holes that we missed in this interview can, It's absolutely fine if you dont want to continue the interview process after today, just let us know.
- Are there any last thoughts or points of information we didn't touch upon that you're itching to get out?
- Any last questions?
- If you would like we can provide you with a transcript or recording of this interview for your own review.
- It was an honor to learn about this passion/specialty of yours.

4) What are your selected roles?:

- Adam: notetaker
- Bryan: primary interviewer
- John John: secondary interviewer and notetaker, main recorder of session

B. Interview Results Interpretation

1) User Need Chart (starts on next page):

Subject:	Stroke-related Hemiplegia Patient	**Interviewers:**	John John Huddleston, Bryan Wong, Adam Saleh
Address:	UC Berkeley	**Date:**	March 8, 2021
Telephone:	N/A	**Currently uses:**	Variety of analog workarounds
Willing to follow-up:	Yes	**Subject Background:**	Berkeley Student

Question/Prompt	**Customer Statement**	**Interpreted Need**
Typical Uses	It is hard to do two arm movements at once...	The product is independently actuated between the two arms.
	Ability to use my arm is greatly dependent upon my mood... If i'm tired or stressed, any time of motion is limited.	The product is easy to use and does not fatigue the user.
	I mostly just use my arm as a stabilizer when like, carrying boxes and things.	The product must be able to support objects when lifting.
	I type just as much as I do in a non-virtual lifestyle.	Activities using DM for electronics are not affected
	I hold the cereal box open and rest it on my stabilizing arm to pour	The product is able to complement existing adaptations for arm movements & dexterity
Likes - current situations	Showering is easy one handed, because normally it	The product is easily usable with the working hand within wet conditions.
	doesn't take more than one hand to wash your hair.	
	Something that is cool is this magnetic necklace device that makes you able to put on a necklace yourself.	The product has fine manipulation to handle pinchable objects.
	I can open those doors with latch handles... but the ones with the twisty doorknob suck.	A wrist-twisting motion would be an improvement over the user's current condition

Fig. 6. User Need Chart Part 1

	My friend gave me… a thing they use for disabled people… a foot pedal, that strums the ukulele for you. It doesn't work very well but it was the nicest thing I've ever received.	The product allows the user to regain some ability they lost due to their disability.
	I have learned how to just strategically get jars open, you know, but I wish it didn't have to be like that.	The product can stabilize objects for the working hand to manipulate easier.
Dislikes - current situations	I can't do a ponytail, which sucks.	The product can manipulate flexible objects like hair
	Apple made the new iPhone big...and typing on one hand is kind of annoying	The product eases grasping and does not limit movement with working fingers
	What's annoying, is that when I try to spread, things like cream cheese. Like the bagel will move. You know, when I'm spreading something. And, like the bagel just as just moving around the plate.	The product can secure objects in place and is relatively low profile
	involving my arm takes a lot of emotional energy, you know like I have to be in a good place mentally just because, like, I get more emotional about arm use because it's so annoying [...] And then you know because of that you don't want to use as much and then because of that it doesn't improve with use. So it's sort of like a vicious cycle	The product doesn't hinder other aspects of dexterity or arm use, yet is low profile and encourages use of the available dexterity.
	You can't buy a whole device just to do one thing.	Product is inexpensive and aids in a variety of tasks
	If I tried to strum a guitar, like my hand probably wouldn't be in the right place.	Product manipulates elbow placement and allows for pinching of hemoplegic hand

Fig. 7. User Need Chart Part 2

	I can't brush my teeth with my right hand… and I can't squeeze toothpaste because it doesn't really work.	When using the product the user's pinching ability should be enhanced.
	something that's difficult is zipping up dresses, like when it's behind you.	The product should not limit the reach of the user.
	Finger movement is the main part of life	The user desires a way to interact with the world in a more dexterous manner.
Suggested Improvements	Why has no one thought about making the standard keyboard easier to type?	The product helps with fine finger movement for typing
	I know there is assistive technology where like, you know, a play or a cutting board has a spike, almost, so it holds the item in place, but I do not have that.	The product can isolate objects to make them easier to interact with
	Went to occupational therapy for seven or eight consecutive months. I was getting a lot of gains. But after like after like four or five months, you stop seeing the most gains	The product is a low-energy therapy device that allows consistent use and therapy with generally low commitment
	I can put electrodes on my arm connected to a machine or not a machine like a little device. And it makes my hand, like, activated, because it's hitting a certain nerve. And so, um, yeah so that was good for just helping stretch out and just giving me some mobility. And just in the sense that that did help with my wrist. But it's something that takes up a lot of a lot of energy and time	The product is a muscle stimulation/therapy device that the user can forget about, yet it still does its job consistently

Fig. 8. User Need Chart Part 3