

Functional MRI-Compatible Orthosis for Hand Grasp Assistance During Robot-Assisted Therapy for Stroke Survivors

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ABSTRACT

Overall stroke hospitalizations have been decreasing in the US, but the number of stroke incidents within the HIV population has been on the rise. Functional MRI (fMRI), which measures the activation patterns in the brain during a particular task, is a way to study the differences between people with stroke only and those with both stroke and HIV, except many potential subjects are being excluded because of spasticity, a condition that prevents them from opening their hands. This exclusion would lead to less representative results, which calls for the need of an orthosis that will assist in hand opening. However, the orthosis must be MR-safe. After experimenting with the Aquahand (a 3D-printed device designed to help stroke survivors with spasticity) and studying hand anatomy, a new design modeled after the biomechanical properties of the hand has been conceptualized and tested in its early stages. Initial results have been promising, with a few modifications having been made to improve the design. The glove will later have to be tested for effectiveness and compatibility with fMRI experiments.

Table of Contents

ABSTRACT	1
INTRODUCTION & BACKGROUND	3
METHODS	5
DESIGN & PROTOTYPE	6
DISCUSSION	8
CONCLUSIONS	9
ACKNOWLEDGMENTS	9
REFERENCES	10

INTRODUCTION & BACKGROUND

About 795,000 people suffer from a stroke each year, with about 610,000 of those people suffering it for the first time [1]. Survivors often have physical disabilities as a result, with about 35% of post-stroke patients having spasticity that requires treatment [2]. In the upper extremities, that spasticity usually presents itself in the flexors, which causes unwanted and excessive flexion in the fingers and wrists [3]. This is a common life-long problem for stroke patients. To counteract the long-term harms of constant flexion, splints may be used to hold the wrists and hands in a functional position [3]. Studies have also shown that with the aid of a glove or an orthosis, those patients who couldn't open their hands previously were then able to do so when fitted with the glove/orthosis [4].

Aside from the problem of spasticity, there has also been the potential issue of increased stroke risk for the HIV population. While the total number of overall stroke hospitalizations decreased by 7% from 1997 to 2006, the total number of stroke hospitalizations with HIV infection rose 60% in that same timespan [5]. This trend is the focus of a larger project study of which this subproject is a part of.

Currently, the project study consists of 12 sessions of therapy bookended by pre- and post-assessments. The goal is to simply determine the effectiveness of the therapy and better understand stroke recovery. However, the focus of this paper is more oriented towards the assessments. In them, a subject's condition is measured through several tests, but the relevant one here is the functional MRI (fMRI) scan. Subjects are instructed to open and close their hands repeatedly (as well as elbows, independently) when prompted by commands on a screen. Doing so provides activation patterns, which can reveal possible changes in neural activity around the infarction and an increase in neural plasticity in the contralateral hemisphere [6]. Seeing these images will aid in understanding stroke recovery. Additionally, they are simultaneously wearing a glove with attached bend sensors, which contribute to the calculation of grasp aperture, defined as the distance between the tips of the index finger and thumb [6].



Figure 1: Glove with bend sensors. Four bend sensors measure the angles of the metacarpophalangeal (MCP) and interphalangeal (PIP) joints of the index finger and thumb.

The problem that arises from asking stroke survivors to open and close their hands on command is that many of them cannot do so on their own, due to the spasticity mentioned above. So far, the only way around this has been to exclude those subjects from the study, leading to a less accurate and less representative understanding of stroke recovery. This paper delineates the design and development of an assistive orthosis/glove that will allow for a greater inclusion of stroke survivors in our study. Because most physically impaired stroke survivors are at least able to close their hands, the design of this orthosis focuses on assisting the opening of stroke survivors' hands.

The orthosis must meet several requirements, however. It must be MR safe, which specifies multiple restrictions, the most notable one being the prohibition of ferrous metals [6]. Also, in order to measure grasp aperture while in the fMRI, the design must take into account the bend sensors of the glove and work around them, while still being small enough to fit in the fMRI machine with the subject [6]. The orthosis must assist and not obstruct.

An additional requirement involves the Activities of Daily Living Exercise Robot (ADLER). A different study used the ADLER to assist in, measure, and track a subject's arm movements during various day-to-day tasks [4]. This was used in combination with an electrically-stimulating glove that assisted a subject in opening and closing his/her hands and performing those daily tasks [4]. Currently, the ADLER holds a subject's arm up by a small cast that is strapped to the subject's forearm. While the electrically-stimulating glove already exists to assist in the opening of a subject's hand, it is preferable if the new orthosis was designed to be compatible with the cast of the ADLER as well.

Finally, the assistive orthosis must actually be effective. This can be determined through the Box and Block Test. Subjects must relocate as many blocks as possible in a given time limit from one side of the box to the other, except a divider is placed between the two sides. A person with spasticity would have much greater difficulty in completing this simple task, and so for the orthosis to be deemed effective, it must significantly increase the number of blocks that are carried over.

METHODS

To have a jumping off point for the orthosis design, an existing one called the Aquahand was 3D printed and tested. It was tried on both personally and with the stroke subjects of the current study for extra feedback, even though they didn't have spasticity. Immediately, there were numerous drawbacks to the design in regards to the requirements detailed above. The most obvious one was the presence of metal extension springs which, while not necessarily ferrous and a problem with the fMRI, can create complications. The other glaring one was that the cuff extended several inches past the wrist, conflicting with the cast of the ADLER.

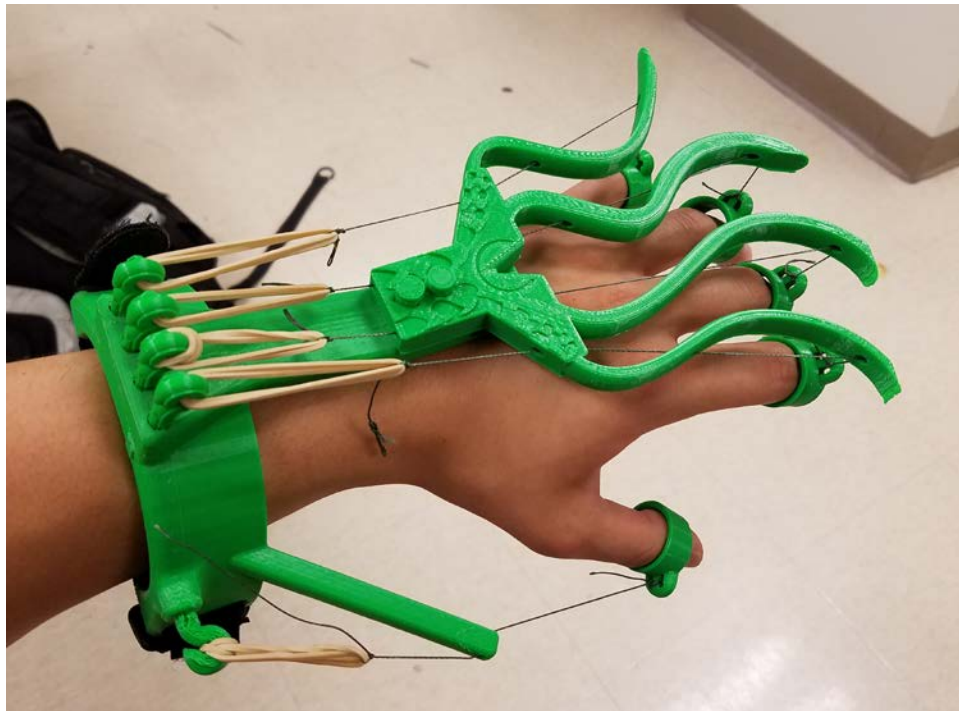


Figure 2: The Aquahand. The device was 3D-printed and assembled using rubber bands. The hand is in the open position.

Issues with function became apparent after assembly and use. Printing the large parts took several hours, and the attempt to take off all the rafts and supports took several more. Each of the finger rings had to be individually tied with fishing wire to a spring, and it was difficult to determine how long that wire needed to be for each finger. While this was not as big of a time issue (in the context of putting together an entire Aquahand),

it was obvious it couldn't be easily adaptable to any specific person, both in terms of the wire length and the size of the rings. The rings also caused an obstruction, getting in the way of grabbing objects. The other large issue was that while one subject who tried the Aquahand required little effort to close her hand, the other subject was unable to do it at all (though again, neither had spasticity). That was despite only one rubber band being used per finger (rubber bands were used as a replacement to the springs). The biggest takeaway was lack of efficient adjustability, both in regards to the size of an individual's hand and the strength of the assistance provided. With all the problems the Aquahand had, it was clear a very different design was needed.

DESIGN & PROTOTYPE

Since the goal of the design was to aid in opening of the hand, inspiration for the new design came from the anatomy and kinesiology of the musculoskeletal system of the hand. Simplified, there are two muscle sets that act in opposition: flexors and extensors [7]. The thumb is controlled by different muscles from the other four fingers, but the mechanism is generally the same [7]. In each finger, the tendons of the extensor muscles attach to the base of each phalanx, pulling on them separately so each joint can individually be straightened [7]. In the case of flexion, there are several "tubes" attached to the bones that, together with the muscles, create a pulley system [7]. Combining these parts gave way to the conceptualization of the new design, which involves 3D printed "phalanges" (proximal, middle, and distal), rubber bands tied to wires, and a 3D printed hook system, all stitched onto a glove. The idea for using a glove as the foundation for the plastic pieces came from the bend sensors that are already inserted on a glove. Combining the two by integrating the assistive device with the bend sensors would create one efficient system.

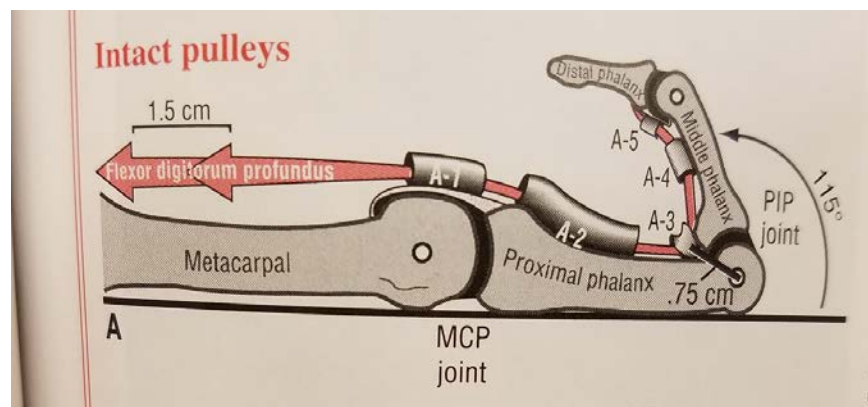


Figure 3: Diagram of the pulley system. This diagram depicts how the pulley system works in creating flexion of the finger.

Initial tests were promising. Pieces for just the index finger were sewn on a test glove, and relaxing the hand led to a straightening of the finger. Because the test glove didn't have full length finger sleeves, only the proximal and middle phalanges were sewn on and tested. Consequently, there was no structure to tie a wire to and connect the rubber bands, so a larger rubber band was instead hooked around the far end of the middle

phalanx. This allowed for rubber bands to be easily added or removed since they didn't have to be tied to a wire.



Figure 4: First test of design. The rubber band is directed through the tunnel of the proximal phalanx.



Figure 5: First test with closed hand. The rubber band is instead hooked around the finger to prevent it from flying off. It is also hooked farther away on the back of the hand to test the multiple locations.

A few problems arose though with the new design. First, there was some difficulty in threading the rubber band through the tunnels. While one rubber band was relatively easy, it became increasingly difficult to put multiple ones through, especially if one was already in place. This led to a bypassing of the proximal phalanx. To fix this, the tunnels were changed to open walls, allowing for multiple rubber bands to be very easily placed over the pieces. Also, because the pieces weren't originally meant to have the rubber bands be hooked around them, they would occasionally fly off. This was quickly fixed by adding a small hook to the far ends of each piece to keep the rubber bands in place. Finally, while the middle phalanx piece was securely stitched to the glove itself, the glove is somewhat elastic and isn't secured to the finger. Therefore, the force of the rubber bands pull the plastic piece away from the finger, especially as more rubber bands are

added. The overall glove still had its desired effect, but it looked unstable. This was in turn fixed by adding a slot for a small Velcro strip that securely fastens the plastic piece to the finger.

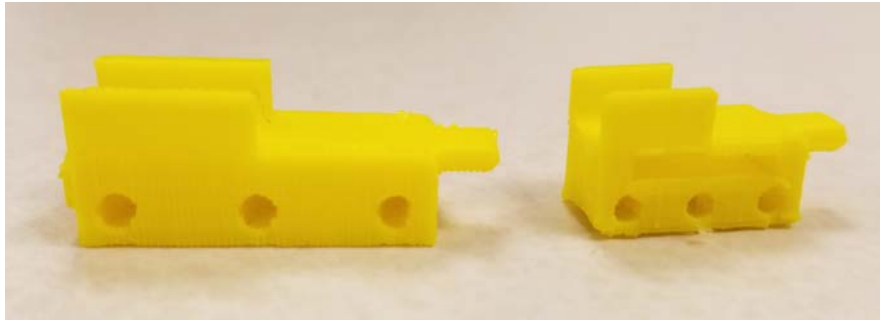


Figure 6: New modifications. The proximal and middle phalanges are shown for the index finger. Both pieces have the new half walls instead of tunnels and the single hooks on one end. The middle phalanx has the Velcro slot added in as well.

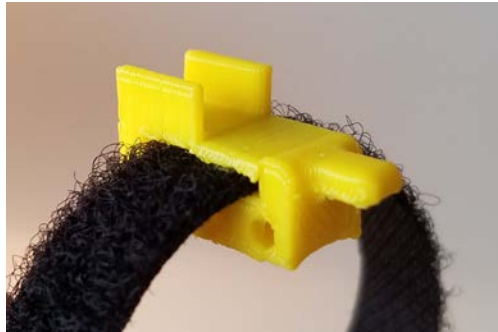


Figure 7: Close-up of middle phalanx. A different angle gives a better view of the walls, and the Velcro strip is inserted to show how it will work.

DISCUSSION

Cerebral plasticity and the mechanisms of stroke recovery are not well understood, and examining activation patterns from the fMRI in the study can lead to improved therapy methods. However, because only a specific group of stroke survivors, ones who have the ability to open and close their hands and elbows, can be studied, any data obtained may not be as helpful in understanding stroke recovery for everyone. That is where this new orthosis design will come in to include many more subjects in the study.

Easily the best attribute of the design is the ease of adjustability, which was the main problem of the Aquahand. A single glove can fit many different hand sizes, and another glove can be made for the rest. The strength of assistance provided can also be immediately adjusted to the individual, as either the rubber bands can be stretched further, more rubber bands can be added, or stronger/weaker rubber bands can be exchanged for. This is an important aspect because when a prospective subject comes in to be assessed, there is no way of knowing beforehand exactly how much assistance needs to be provided. It isn't until the subject tries on the glove to see what level of

assistance is necessary, and with the new design, the glove can be very easily adjusted on the spot to fit the individual. Also, a secondary effect that results from the built-in adjustability of provided force is to have an arbitrary measure of the subject's condition. If, say, a rubber band needed to be stretched to the farthest hook on the hand during the pre-assessment but only to the nearest one during the post-assessment, there is a somewhat objective indication of an improvement in the subject's spasticity. This may not be a test that rises to the level of the Fugl-Meyer, but it could still provide additional information.

The main potential cons at this point would include amount of time and money it could take to make the devices, as the gloves had to be altered and each individual plastic piece had to be stitched in. However, because every piece is plastic, the materials are cost effective and fully MR safe, and because the glove only covers the hand, there is minimal obstruction during use and is compatible with the ADLER.

CONCLUSIONS

Currently, as the device has yet to be fully built, the finished product must be tested for its effectiveness and compatibility with the fMRI. This could mean having a healthy person be scanned in the fMRI, opening and closing his/her hand, once with the glove and once without. This would confirm that the glove creates no noise in the fMRI environment if both activation patterns are virtually identical. The effectiveness of the assistive glove would be tested using the Box and Block Test. A subject may even use the new design for one attempt and then the Aquahand for the next to compare the effectiveness of each design.

Once a full glove is made, there may be even more reservations about the design, and other modifications could be made. Hopefully however, this design, or at least a close relative, will prove to be useful and applicable in the ongoing study and include those with spasticity. The glove may even be able to allow stroke survivors to use at home for everyday use, furthering its impact in the stroke community. Future directions would include looking to include even more subjects, such as those who have hemiparesis and are unable to neither open nor close their hands, either by expanding this design or creating an entirely new one. Maximizing the number of eligible stroke patients in the study is the ultimate goal.

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