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HAND MOVEMENT GLOVE FOR CHILD WITH TITINOPATHY

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ABSTRACT

Patients with titinopathy or hand paralysis often lack quality, low cost therapeutic tools to aid in gaining hand strength and range of motion. As a result, our team sought to develop a way to increase flexion and passive motion in the hand of a patient with titinopathy in order to gain functionality. This paper outlines the design and development of a novel therapeutic glove for a 4 year old boy with a neuromuscular disease that prevents him from flexing the two distal joints of his fingers.

The team has developed a low-cost hand movement glove (HMG) to be used as a supplement to traditional physical therapy. The device utilizes a motor-cable system secured to each finger, allowing for independent and synchronized flexion of each finger. Phase I of prototyping resulted in a working model to assess the finger movement mechanism and overall wearability of the device. Phase II utilized an Arduino Uno microcontroller, circuit switch, PCA9685 driver board, micro servo motors, a cotton woven glove, and 3-D printed components to characterize a more robust model allowing independent flexion of each finger.

Initial testing has proven the device's ability to achieve physiologically relevant degrees of flexion in each finger. Upon completion of further testing, we anticipate this device having a profound impact as an additional tool utilized in the patient's physical therapy regimen to allow for regained flexion at both proximal and distal interphalangeal joints.

Keywords: titinopathy, hand paralysis, hand movement, pediatric device, hand glove

1. INTRODUCTION

Lack of ability to move a hand or fingers prevents the ability to perform everyday tasks, such as holding a pencil, brushing your teeth or opening a can of food. Many neurological diseases or traumatic events (e.g., hemiplegia after a stroke), cause patients to lose full function of their extremities. While the team initially sought to develop a therapeutic tool for those suffering from stroke-resultant hemiplegia, the team was contacted by a Texas A&M University alumna who was looking for a device for her 4-year-old son with titinopathy, which is a muscular disorder caused by the congenital malformation of the titin protein. The patient is unable to move his distal interphalangeal (DIP) and proximal interphalangeal (PIP) finger joints, preventing him from performing daily tasks.

Current treatment for loss of hand function focuses on restoring motor functionality through muscular training and movement therapy. While there are medical devices and gloves on the market to address this indication, these devices only operate two to three fingers at a time [1,2,3], do not enable full flexion of the finger or only focus on extension [4], and are not indicated to strengthen finger muscles passively. Many of these devices are bulky and require large battery packs or being plugged into an outlet to operate [5,6,7].

FIGURE 1: EXAMPLE OF HAND WITH RARE TITINOPATHY

2. MATERIALS AND METHODS

2.1 Design Inputs

We interviewed the family of the intended recipient of the hand glove as well as his physical therapist. Together, the family and physical therapist identified needs for the glove as well as design inputs. The parents wanted to ensure the glove could be worn for over 30 minutes at a time, was comfortable to wear and was easy to keep charged. The physical therapist recommended a passive, therapeutic glove that could be used to re-train the muscles of the finger and supporting structures surrounding the DIP and PIP joints with the goal that the patient may be able to move his hands on his own after frequent use of the device. The responses and recommendations were documented and then the authors consolidated the feedback into design inputs to integrate into the prototyping and testing. With these considerations in mind, a hand movement glove (HMG) was developed with the aim of supplementing physical therapy at home for retraining of the neuromusculature of the fingers, allowing for more precise motor control.

2.2 Design Ideation Process

The hand glove prototype combines aspects of motor-operated cables and a glove application apparatus into a hybrid model.

The team subsequently focused on the following parameters while planning and constructing the device: (1) comfort of the device wearer, (2) significant force generation to evoke finger movement without injury, (3) ease of use and operation, (4) lightweight design, (5) non-invasive mechanism, and (6) low cost of manufacturing. The team is optimizing the final iteration to be low profile and adaptable to fit multiple hand sizes.

The final design will incorporate the aforementioned design inputs indicated by the stakeholders, as well as the ability to use for 30 mins to one hour at a time at home without the assistance of a physical therapist. Upon completion of an initial concept ideation phase, the team opted to design a low-cost glove device that could be used to supplement regular physical therapy. This would be accomplished using a synchronized motor-cable system secured to each finger, and mounted on a glove that the child can wear comfortably, to help strengthen muscles in the hand by inducing passive movement of the fingers. To prevent regulation barriers, the device will be designed as a Class 1 device.

2.3 Prototyping

Phase 1

During the initial prototyping phase, the team addressed key prototyping challenges, including the design of the circuit that the device will use, which type of motor will operate finger movement, and how to mount the system on the glove that the patient will wear. Additionally, the team needed to ensure that the device could be worn for long periods of time by ensuring comfortability. For the original circuit, an esp32 microcontroller running on a 5V battery was connected to a DC motor. This motor was then mounted to the palmar surface of the wrist of a cotton-woven glove and connected to one fingertip with a polyethylene fiber cord for testing purposes. A potentiometer was also connected to the circuit for control of the motor. The motor was mounted to the glove via a 3D printed polylactic acid (PLA) raft. The raft was secured to the glove via cyanoacrylate adhesive. This setup allowed for an initial working model to test the finger movement mechanism and assess the comfortability of the glove (Figure 2).

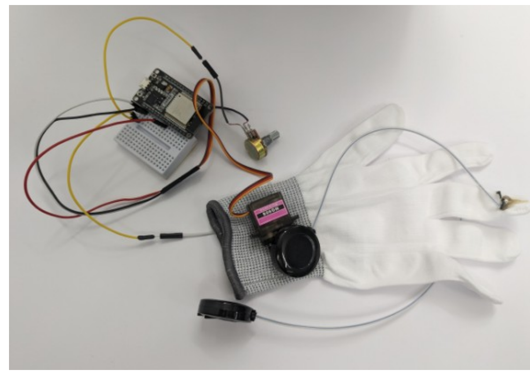

FIGURE 2: FIRST WORKING PROTOTYPE OF HAND MOVEMENT GLOVE DEVICE

Phase 2

After initial testing of the prototype, an assessment of device functionality was made regarding the original design parameters. Upgrades to the prototype were subsequently made according to this assessment. Sufficient functionality of the motor-cable system was achieved with regard to bending the fingers at the DIP and PIP. To incorporate multiple motors so that all fingers are able to be bent in coordination, a PCA9685 driver board was added to the circuit to operate each motor. The original esp32 microcontroller was also replaced with a Arduino Uno microcontroller for compatibility with the PCA9685 driver board. Additionally, to achieve optimal power efficiency each DC motor was replaced with a servo motor. By using servo motors, each motor only rotates 180 degrees, versus a DC motor that rotates 360 degrees in the Phase 1 prototype. This also allows the servo motors to run on a sweep function to produce passive, therapeutic bending at the DIP and PIP joints. The potentiometer was replaced with a circuit switch for easier device operation. The circuit runs on a 6V battery to provide adequate voltage for the microcontroller, servo motors, and driver board. In this Phase 2 device, each servo motor was attached via a polyethylene fiber cord to a 3D printed PLA fingertip cap. The servos were also mounted on the dorsal side of the glove in this iteration, with each cord running along the backside of the finger, so that the holding of objects within the palm was not impeded while using the device. We realized that the little finger requires significantly less force to bend as well. Therefore, we opted to use only 4 servo motors, connecting the cables for both the little finger and ring finger to one motor. All movement and circuit elements were mounted to the glove via

3D printed PLA rafts secured to the glove with cyanoacrylate adhesive, as in the phase 1 model (Figure 3). This model of the device allows for more complete, fluid, and effective movement of each finger and does not hinder grasping of objects while the device is being worn.

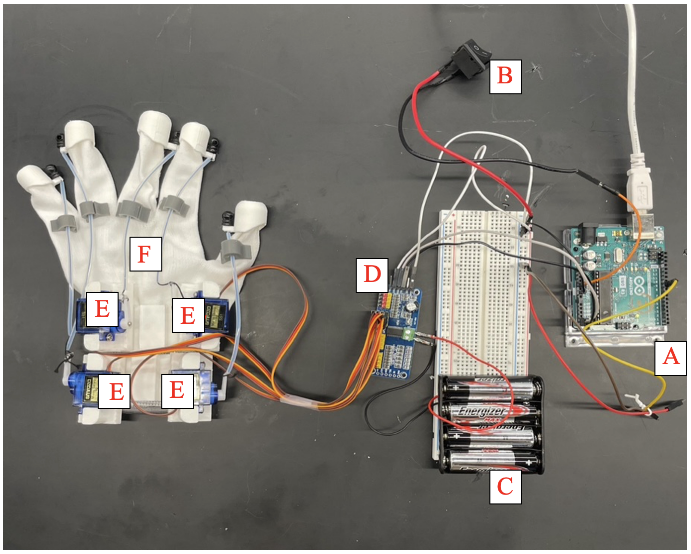

FIGURE 3: CURRENT WORKING PROTOTYPE OF HAND MOVEMENT GLOVE DEVICE *[A - Arduino Uno microcontroller, B - circuit switch, C - 6V battery, D - PCA9685 driver board, E - micro servo motors, F - cotton-woven glove]*

2.4 Unexpected Barriers

When designing the glove, initial barriers arose in Phase 2 prototyping with functionality of the servo motors. Occasionally, a servo motor would stall while bending its respective finger, as it was not able to generate enough torque using small, plastic internal gears. The team realized higher quality servo motors were needed in order to continue the motion at the torque needed to move the fingers. The servos with small, plastic gears were replaced with servos with larger, metal gears, raising the manufacturing cost of the device from approximately $25.00 to approximately $35.00.

3. RESULTS AND DISCUSSION

3.1 Initial Testing

Initial testing has included battery endurance, maximal temperature of the circuit elements, glove comfortability, and finger flexion capability. Battery endurance was tested by continuously running the motors of the device until the 6V battery died. The device was able to operate for 64 minutes at maximal charge. Temperature assessment was achieved by operating the device continuously for three hours (180 minutes) and measuring the temperature of each circuit element at the end of this operation period with an integrated circuit (IC) temperature sensor. None of the circuit elements (battery, microcontroller, driver board, servo motors, or circuit switch) reached a temperature above room temperature (22 degrees Celsius) at any point during the operation period. Each team member also tried on the device to test for comfort and ensured there was no pinching, scraping, or uncomfortable range of motion when operating the device.

To test the degree of finger flexion that the device can achieve, one team member operated the device on their own hand while another team member measured the angle of flexion at the DIP and PIP. With each unflexed joint defined as 0 degrees, the device was able to achieve physiologically relevant degrees of flexion in each finger (Table 1, Figure 4, Figure 5).

TABLE 1: DEGREES OF FLEXION

	Thumb	Index Finger	Middle Finger	Ring Finger	Little Finger
DIP*	N/A	75°	67°	62°	23°
PIP**	92°	53°	93°	88°	36°

*DIP = Distal interphalangeal joint
**PIP= Proximal interphalangeal joint

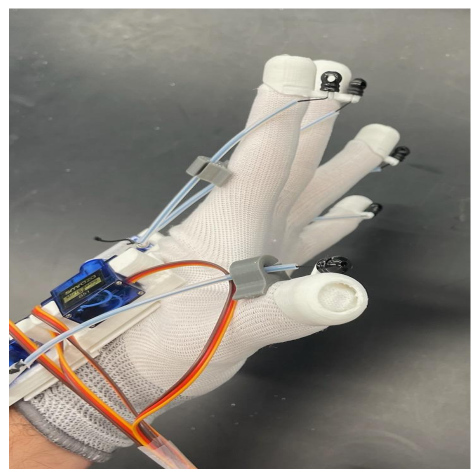

FIGURE 4: UNFLEXED HAND BEFORE DEVICE OPERATION

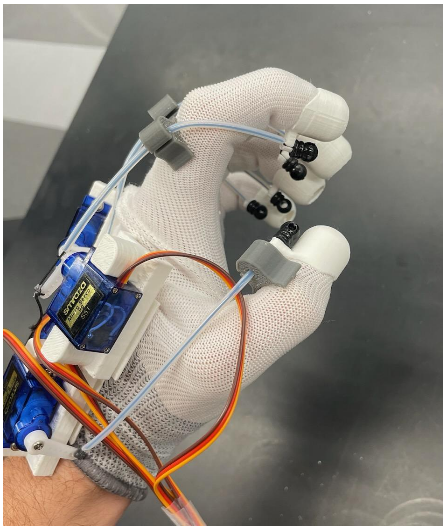

FIGURE 5: FLEXED HAND AFTER DEVICE OPERATION

3.2 Discussion

The hand movement glove device is intended to be used passively by the patient as a therapeutic device to enable motion and increase flexibility in the affected hand. The device can also be used in conjunction with traditional physical and physical therapies. Our device is lightweight, low cost, and can be personalized for the degree of titinopathy in the patient by adjustment of motor torque and power. Although there are devices in the market with similar indications, these devices only operate two to three fingers at a time [1,2,3], do not enable full flexion of the finger or only focus on extension [4], and are not indicated to strengthen finger muscles passively. Furthermore, our device is more compact compared to other devices on the market [5,6,7] by using a small battery and micro servo motors to allow for pediatric use of the device.

3.3 Further Testing, Next Steps and Implications

Subsequent development of this device will focus on five key areas. (1) The existing model will be scaled down to fit our pediatric patient's hand. The Phase II prototype operates effectively in producing physiologically relevant degrees of flexion (Table 1). As the device is adapted for the pediatric patient, we will ensure that the range of flexion remains intact. (2) We will add a protective casing for the device to make it amenable for everyday use such that cables do not detach. (3) Future development will include additional cable attachment points at each finger joint to allow for flexion of the PIP independent from the DIP and vice versa. (4). This technology will also be adapted for patients in permanent flexion, such as cystic fibrosis, so that they can reach extension upon motor activation. (5) We will conduct clinical studies to evaluate the therapeutic performance of our device in improving hand muscle strength from baseline.

Further testing of the device will involve connecting with the child and his family to test the prototype's effectiveness. We will ask the child to wear the glove to determine if the glove fits properly over his affected hand. Next, we will turn the glove on and assess if the motors exert enough force to extend all five fingers completely. We will also assess if the on-off mechanism of the glove will allow for the child to return to his natural flexed position intermittently after fully extending his fingers. Lastly, we will obtain a torque gauge to quantify the amount of torque that each servo motor is applying to each finger.

In terms of future applications, a number of other neurological disorders also present with hand weakness including multiple sclerosis, peripheral neuropathy, epicondylitis, cystic fibrosis, etc. This technology could also be used by patients suffering from hemiplegia after a stroke. We are in the process of acquiring IRB approval to test our device, and anticipate recruiting patients from a variety of neuromuscular backgrounds to test the efficacy in improving muscle strength.

4. CONCLUSION

Using this low cost, high fidelity hand glove, our patient will be able to utilize this passive therapy in conjunction with his scheduled physical therapy sessions to assist in the strengthening of the muscles of his hand and hopefully regain functionality of his DIPs and PIPs. The subsequent efficacy testing after completion of the final glove prototype will dictate if the team proceeds with exploring other applications of this glove as a therapeutic method, such as for patients who have had strokes or other neuromuscular degenerative diseases.

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