Design & Development of a Wrist-Hand Orthosis for Individuals with a Spinal Cord Injury

Amber Gatto, Stephen Sundarrao, and Dr. Stephanie Carey, *Member, IEEE*

Abstract—
Among quadriplegic SCI patients, studies have shown that restoring arm/hand function is their highest priority. This study tested a student designed wrist-hand orthosis (WHO) on healthy subjects to assess its feasibility in helping individuals with a SCI in grasping abilities and independently completing activities of daily living (ADLs). Two prototypes were created, but early on it was concluded that the first prototype was more suitable to move forward with testing. Each participant used the WHO to complete a variety of ADLs. Results showed that healthy subjects had little to no difficulty completing all ADLs, with the exception of independently donning/doffing the orthosis. Some ADLs could be difficult for the SCI population to complete, however, the next study, in which OpenSim will be used to model muscle activation during ADL motions and estimate the forces associated with those motions, will be vital in determining whether the WHO is a feasible option for the SCI population.

I. Introduction

According to the most recent data available through 2016, the United States has approximately 282,000 persons living with a spinal cord injury (SCI), and that number is estimated to increase by nearly 17,000 new cases each year [1]. Between 45%-60% of all reported SCI cases are classified as incomplete quadriplegia, ranking it as the most common category of SCI [1, 2]. The majority of cervical spinal cord injuries occur in the C5-C7 segments, which cause patients to lose upper and lower limb functionality, along with loss of the ability to control certain bodily functions [3]. Among quadriplegic SCI patients, studies have shown that restoring arm and hand function is their highest priority, therefore, providing them the ability to grasp objects will allow for independent completion of activities of daily living (ADLs) that would otherwise need assistance [3, 4, 5, 6]. Patients with an incomplete C5-C7 SCI, lose prehension abilities, but wrist function is almost universally retained [3, 7, 8, 9], thus most prehension rehabilitation techniques apply the tenodesis grasp and release effect. This orthopedic phenomenon takes advantage of retained wrist function and is achieved through wrist extension for grasping and wrist flexion for releasing [7, 8, 10]. However, these motions are exactly opposite to the way able-bodied individuals grasp and release objects. Given that approximately 90% of all SCI cases are non-congenital, the target population was able-bodied prior to their SCI, therefore, if grasping could be achieved through more intuitive motions, rehabilitation could be easier for patients [1,2]. Current wrist-hand orthoses (WHOs) may help with ADL completion, providing some degree of independence, but they cannot be donned/doffed (put on/take off) independently [11], meaning, individuals with a SCI never feel a complete sense of independence.

II. Wrist Hand Orthosis

A. First Prototype

This technology is a student-designed powered wrist-hand orthosis (WHO) designed to help individuals with a C6- C7 spinal cord injury (SCI) independently complete activities of daily living (ADLs). This WHO utilizes a modified tenodesis grasp to operate in a more intuitive manner, allowing for whole-hand gripping and completion of more ADLs. The traditional tenodesis effect takes advantage of retained wrist function and is achieved through wrist extension for grasping and wrist flexion for releasing. However, these motions are exactly opposite to the way able-bodied individuals grasp and release objects. Given that approximately 90% of all SCI cases are non-congenital, the target population was able-bodied prior to their SCI, therefore, if grasping could be achieved through more intuitive motions, use of assistive devices would be easier for patients [8, 9].

There are only two mechanical linkages: a thumb linkage and an index finger linkage, each configured with a slight angle to mimic the natural bend in fingers during grasping/releasing motions (Figure 1).

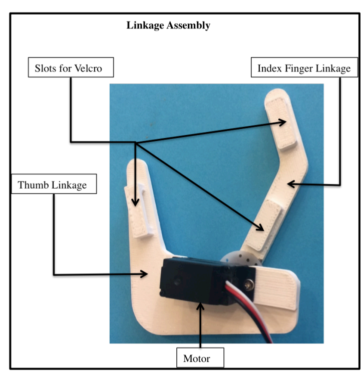

Figure 1: Linkage Assembly

The current prototype requires securing linkages to respective fingers creating a pincer-like design; index, middle, ring and little fingers are bound as one side and the thumb acts as the other side (Figure 2).

A.G is with the University of South Florida, Department of Mechanical Engineering, Tampa, FL: (561-317-9587; ambergatto@mail.usf.edu)
S. S. is with the University of South Florida, Department of Mechanical Engineering, Tampa, FL: (813-974-5346; sundarra@usf.edu)
S. C. is with the University of South Florida, Department of Mechanical Engineering, Tampa, FL: (813-974-5765; scarey3@usf.edu)

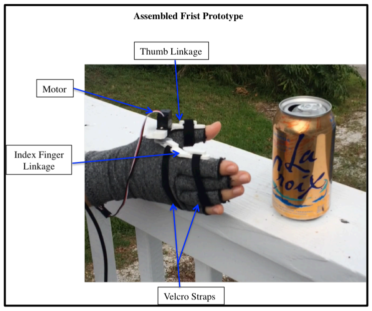

Figure 2: Assembled First Prototype

This orthosis operates via wrist motion input that is detected by a flex sensor on either the dorsal or ventral side of the wrist (Figure 3). Wrist flexion sends a signal to the motor, driving the linkages (and by extension the fingers) into a grasping motion. Conversely, wrist extension creates a releasing motion.

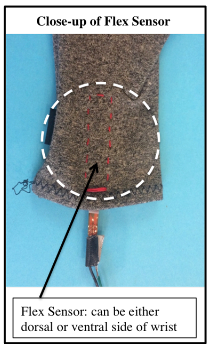

Figure 3: Close-up of Flex Sensor in First Prototype

B. Second Prototype

Initial feedback on the first prototyped WHO pointed out a key challenge with our design; it cannot be donned/doffed (put on/taken off) independently. Current wrist-hand orthoses (WHOs) may help with ADL completion, providing some degree of independence, but they also cannot be donned/doffed independently, meaning, individuals with a SCI never feel a complete sense of independence [3,4, 5, 6]. A device embodying this ability will give users a more complete sense of independence when performing ADLs. It was hypothesized that designing an orthosis don/doff stand would provide the most practical solution for independent donning/doffing. Since designing the stand, the design of the WHO needed to be slightly altered (Figures 4 and 5).

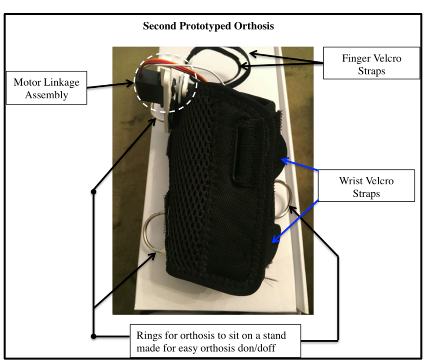

Figure 4: Second Prototype of Orthosis

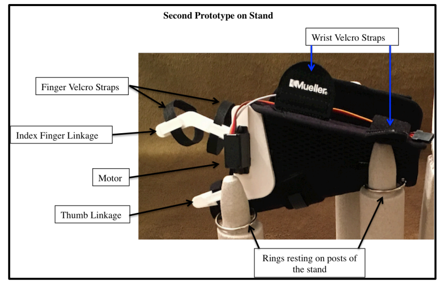

Figure 5: Second Orthosis on don/doff stand

III. Methods

This study showed orthosis feasibility. Before testing on the target population, our protocol was to test on healthy subjects without hand injuries. This approach demonstrated the orthosis as a workable design. Participants were instructed to completely relax their hand, not use their own grip ability, and allow the device to control their fingers during grasping.

Testing began with each participant donning the orthosis and completing a series of ADLs. Participants used the WHO to complete ADLs involving feeding, grooming, and donning/doffing the orthosis. These activities are a compilation of ADLs that specifically assess unilateral hand performance of individuals with a SCI [2, 3, 12]. The activities chosen have the greatest likelihood of being completed with this orthosis. Excluded activities, such as acute digital manipulation, are not in the design scope of this orthosis. Success was based on whether the individual could fully complete the task. The activities of daily living included:

- Feeding
  - Pick up empty and full cup/glass/mug. Drink from full cup/glass/mug
  - Pick-up (horizontal/vertical orientation) & use utensils
  - Pour liquids
- Grooming
  - Picking up tooth brush (horizontal/vertical orientation) and brush teeth
  - Brushing/Combing Hair (horizontal/vertical orientation)
- Other
  - Independently Don/Doff orthosis

IV. Results

A. Lessons Learned from Second Prototype

The second prototype, in conjunction with the don/doff stand, provided enough stability that it could be donned/doffed independently, however it no longer allowed for unencumbered wrist movement, meaning the motor could not be activated and ADLs could not be completed. For this reason, participants used the first prototype to complete the ADL testing.

B. Results from Completion of Activities of Daily Living

Participants were able to easily grasp all items placed in a vertical orientation. That is, each had the ability to grasp tapered drinking cups, mugs, and common cylindrical beverage containers on the first attempt. Items that are typically found in a horizontal orientation (utensils, tooth brush, hairbrush, comb) were more difficult for the users to grasp, however, given that participants were healthy subjects, the task was able to be completed after multiple attempts. When these same items were placed in a vertical orientation, participants were able to easily grasp all items. For example, a toothbrush was placed the toothbrush in a holder and the toothpaste was designed to stand in an upright position. Similar solutions were applied to the other items, such as the hairbrush, comb, and utensils. Again, since testing was completed on healthy subjects, there was not any difficulty in picking up and using any of the items.

Finally, in order to test the feasibility of whether the orthosis could be donned/doffed independently by an individual with a SCI, participants were told they could only use their other hand in the same way an individual with a SCI would use their other hand to aid in donning/doffing. That is, participants could only use their thumb to hook through Velcro loops or use thumb and index finger to grasp and fasten/unfasten the Velcro strips. Since the second prototype (which could be donned/doffed independently by healthy subjects but did not allow for wrist flexion/extension) was not used, participants could not independently don/doff the orthosis.

V. Conclusion and Future Work

This study was designed to see if this orthosis would be feasible in helping individuals with a SCI grasp items and independently complete activities of daily living.

First, although the second prototype allowed for independent don/doff, it did not allow for adequate wrist motion, therefore, the next prototype will combine the freedom for wrist motion from the first iteration with the stability for donning/doffing from the second iteration. Further iterations could also implement a variable assistance motor, which would provide individuals the ability to control the level of assistance. This variable assistance feature also means other patient types, such as stroke patients, or elderly patients who have lost grip strength, can use this device for either rehabilitative (worn for a short period of time during a rehab routine) and/or assistive purposes (worn more permanently throughout the day).

Second, if an individual with a SCI were to use the orthosis to complete the same ADLs, depending upon their ability to achieve a large open hand position, grasping a typical ceramic mug may be more difficult to securely grasp. Additionally, items typically found in a horizontal orientation would be difficult for these users to grasp. However, the task could be completed under two possible circumstances: 1) depending upon the object, success may be achieved after multiple attempts, or 2) design modifications could possibly be implemented to allow completion of that specific task. If neither are feasible options for the user, the object may need to always be placed in a vertical orientation. For example, a toothbrush is often found in a horizontal orientation, however, it can be placed in a toothbrush holder, making it easier to grasp. Another example is toothpaste that stands in an upright position. Further, depending upon the users' muscle capacity, picking up heavier items such as a full glass or ceramic mug may be difficult.

The next step in testing the feasibility of this orthosis is to conduct a follow-up study in which participants will use the WHO to perform ADLs in front of a motion capture system. That motion capture data will then be visualized in OpenSim, an open source simulation software. First, the orthosis Computer Aided Design (CAD) model will be added to an existing OpenSim upper limb model. The motion capture data will then be visualized in OpenSim to model muscle activation during ADL motions and estimate the forces associated with those motions. OpenSim will be used to 1) determine which muscles are activated during each ADL task in order to establish if the current orthosis configuration will be practical for an individual with a SCI, 2) define adjustments required for individually customized orthoses by optimizing key features and parameters of the orthosis during the on-going prototyping phase, and 3) determine the effects the prototyped orthosis has on the human body.

References

[1] National Spinal Cord Injury Statistical Center (2016). Spinal cord injury (SCI) facts and figures at a glance.

[2] Kalsi-Ryan, S., Beaton, D., Curt, A., Duff, S., Popovic, M. R., Rudhe, C., ... & Verrier, M. C. (2012). The graded redefined assessment of strength sensibility and prehension: reliability and validity. *Journal of neurotrauma*, *29*(5), 905-914.

[3] Thorsen, R., Dalla Costa, D., Chiaramonte, S., Binda, L., Beghi, E., Redaelli, T., ... & Ferrarin, M. (2013). A noninvasive neuroprosthesis augments hand grasp force in individuals with cervical spinal cord injury: The functional and therapeutic effects. *The Scientific World Journal*, *2013*.

[4] Simpson, L. A., Eng, J. J., Hsieh, J. T., & Wolfe and the Spinal Cord Injury Rehabilitation Evidence (SCIRE) Research Team, D. L. (2012). The health and life priorities of individuals with spinal cord injury: a systematic review. *Journal of neurotrauma*, *29*(8), 1548-1555.

[5] Harvey, L. A., Dunlop, S. A., Churilov, L., Galea, M. P., Hands, S. C. I. P. A. S., & Collaborators, O. T. (2016). Early intensive hand rehabilitation is not more effective than usual care plus one-to-one hand therapy in people with sub-acute spinal cord injury ('Hands On'): a randomised trial. *Journal of physiotherapy*, *62*(2), 88-95.

[6] Mateo, S., Di Rienzo, F., Bergeron, V., Guillot, A., Collet, C., & Rode, G. (2015). Motor imagery reinforces brain compensation of reach-to-grasp movement after cervical spinal cord injury. *Frontiers in behavioral neuroscience*, *9*.

[7] Di Rienzo, F., Guillot, A., Mateo, S., Daligault, S., Delpuech, C., Rode, G., & Collet, C. (2015). Neuroplasticity of imagined wrist actions after spinal cord injury: a pilot study. *Experimental brain research*, *233*(1), 291-302.

[8] Price, G. (2004, September). There is little published evidence to support or refute the use of passive ranging to improve tenodesis hand function in people with C6 quadriplegia, in the first 6 months post-injury. Retrieved from http://www.otcats.com/topics/Glenda_Price_2004.html

[9] Mateo, S., Roby-Brami, A., Reilly, K. T., Rossetti, Y., Collet, C., & Rode, G. (2015). Upper limb kinematics after cervical spinal cord injury: a review. *Journal of neuroengineering and rehabilitation*, *12*(1), 1.

[10] Nas, K., Yazmalar, L., Şah, V., Aydın, A., & Öneş, K. (2015). Rehabilitation of spinal cord injuries. *World journal of orthopedics*, *6*(1), 8.

[11] Ates, S., Leon, B., Basteris, A., Nijenhuis, S., Nasr, N., Sale, P., ... & Stienen, A. H. (2014, June). Technical evaluation of and clinical experiences with the SCRIPT passive wrist and hand orthosis. In *Human System Interactions (HSI), 2014 7th International Conference on* (pp. 188-193). IEEE.

[12] Collinger, J. L., Wodlinger, B., Downey, J. E., Wang, W., Tyler-Kabara, E. C., Weber, D. J., ... & Schwartz, A. B. (2013). High-performance neuroprosthetic control by an individual with tetraplegia. *The Lancet*, *381*(9866), 557-564.