3D Printed Stroke Rehabilitation Exoskeleton Design

Limitations and Barriers of Exoskeleton Rehabilitation Adoption

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

According to the CDC, stroke is the leading cause of long-term neurological disability and a leading cause of death in the United States. Strokes occurs when a blockage or vessel rupture disrupts blood flow, which carries oxygen and nutrients, from reaching the brain. The severity of post-stroke conditions vary depending on the obstruction's location and the extent of brain tissue affected. Physical complications include spasticity and decrease in muscle strength, which can lead to long term pain or discomfort for patients. Progressive decrease in muscle movement due to loss of muscle fiber cross-sectional area is also experienced by patients. As a result, basic tasks can be difficult to accomplish.

Stroke rehabilitation can substantially improve a patient's function. While it does not reverse their brain damage, it can help them regain independence. One method of receiving rehabilitation is through visiting physical therapists who work through exercises and stretches with patients. Occupational therapists can also be visited to receive help practicing daily tasks like eating and bathing. Additional rehabilitation techniques include mirror therapy, bilateral movement training, and mental imagery training.

Robot-aided therapy has been sought after in the stroke rehabilitation world due to its claims for shortening hospitalization time and minimum need of human intervention. In efforts to provide post-stroke patients an improved quality of life and means to regain muscular function, my capstone team will design and prototype a 3D printed low-cost exoskeleton. It will provide patients upper limb rehabilitation, specifically the shoulder and elbow, through the use of stepper motors, pneumatic artificial muscles, and sensors. Exoskeletons offer advantages such as resolving the issue of human costs involved in rehabilitation programs and providing reliable and controlled exercises. While the use of robotics in stroke rehabilitation is promising, an engineer's exoskeleton design is only valuable if stroke patients are willing to employ it. Therefore, in addition to producing a working exoskeleton, I will investigate what aspects and factors influence stroke patients to pursue exoskeleton rehabilitation.

Technical Topic: 3D Printed Stroke Rehabilitation Exoskeleton Design

The most common stroke rehabilitation treatment of seeking out therapists who provide guidance through exercises will not be able to support the number of patients projected in the near future. Additionally, “therapist-led rehabilitation treatments require intensive labor, and typically are time-consuming” (Chen et al., 2020, p.1). Robotic exoskeletons address this problem by allowing patients to perform exercises with minimal need of therapists or supervision. Exoskeletons are a type of wearable technology that “replace diminished or lost limb functionality, helping people regain some ambulatory freedom” (Greenbaum, 2015, p.1). Although some studies have concluded that patients are able to increase their ability to perform everyday tasks while wearing exoskeletons, many of these devices are heavy, which limits the patient’s availability to receive rehabilitation. Additionally, one study determined that the average total cost of therapy for receiving robot-assisted therapy was comparable to that of receiving intensive comparison therapy (Lo et al., 2010).

To address concerns of current exoskeleton designs, my capstone team’s project will use materials and devices that are low cost and lightweight to operate an upper-limb exoskeleton. The code we will develop to control the exoskeleton will be open-source in order to make our design accessible to other engineers and encourage future design improvements. Our exoskeleton is a passive device, targeting stroke patients with mild impairment, and will consist of three degrees of freedom that allows for flexion-extension in the elbow, flexion-extension in the shoulder, and abduction-adduction in the shoulder. The exoskeleton will aid the strengthening of muscles as the patient wears the exoskeleton while completing slow and repeatable rehabilitation movements and exercises.

The body of the exoskeleton will be 3D printed with cheap and lightweight materials such as ABS or PLA plastics. We will continue to adjust our print design as we test multiple CAD iterations and learn from published designs. To aid movement during rehabilitation exercise, two stepper motors will direct the shoulder housing and a pneumatic actuator will direct the elbow. My capstone team aims to use motors and actuators that are small, inexpensive, and are durable enough to withstand use during rehabilitation programs. To address the challenge of working with smaller DC electric stepper motors that possess smaller magnitudes of holding torque, we will pair the motor with a gearbox to increase the torque available to drive a load (Gandolla et al., 2020). Pneumatic artificial muscles (PAM) simulate the shortening and lengthening behavior of natural muscles by filling pressurized air in a pneumatic rubber bladder. Although they have an issue of not completely returning to their initial position after repeated motions, “overall performance is adequate for application of robotic training for impaired individuals” (Chen et al., 2020, p.11). By testing the reliability of the sensors, which will gather information from the patient’s muscle signals, we will be able to gather information on the range of motion and generated force of the motors and PAM. The sensors we will use are inertial measurement unit (IMU) sensors, which will relay information about the current position of the arm, and electromyography (EMG) sensors, which will track the muscle activity.

STS Topic: Limitations and Barriers of Exoskeleton Rehabilitation Adoption

Every forty seconds, someone in the US has a stroke and often they will struggle with muscular issues afterward. While designing a possible solution to support post-stroke challenges is important, it is also necessary to account for the patient’s perception of my capstone device. A rehabilitation exoskeleton may be a prime medical device. There is a voiced demand of exoskeleton use by patients and individuals with mobility impairments. After evaluating several designs and learning about the potential health and social benefits of using exoskeletons, a survey found that wheelchair users were eager to use and recommend an exoskeleton (Wolff et al., 2014). However, it is important that the interaction of social groups and the technology is taken into the design. Barriers and benefits of exoskeletons presented by patients, physical therapists, the healthcare system, and engineers will be investigated by reviewing case studies on various exoskeleton designs with the lens of actor-network theory.

Many exoskeletons have been designed and developed since 2000 but many of them have never been used by target population (Heide et al., 2014). One explanation can be accredited to the poor cost-benefit ratio of these devices. Selection of assistive devices is restricted by limited reimbursement options and availability (Janssen et al., 2019). In many case studies, many participants listed the financial burden of purchasing access to an exoskeleton turned them away from the possibility of using the technology. Additionally, “vast majority of these devices may be used only at therapeutic institutes since they require supervised assistance from qualified personnel” (Maciejasz et al., 2014, p.12). Engineers and the healthcare system have presented many barriers for patients to be introduced to exoskeletons due to the expensive cost of their designs and prohibiting personal from the target population.

Patients that require less intensive rehabilitation exercises and programs prefer home-based therapy rather than visiting a hospital or rehabilitation center. Therefore, various exoskeleton designs are targeting the goal of transforming complex devices to be simplified and adaptable to the home. As a result, the issue of a shortage of physical therapists and the worry of patients not receiving sufficient care or meeting their rehabilitation goals will be alleviated. It was noted in a study on patient and staff acceptance of robotic technology in occupational therapy that, “many therapists may stop using devices if set-up takes more than 5 minutes” (Maciejasz et al., 2014, p.12) Therefore, a new problem emerges with the adoption of exoskeletons in that if physical therapists, a figure that patients look towards for help, find the device bothersome to set-up then patients will mirror the same opinion.

In addition to a patient’s use of exoskeletons improving their functional abilities, studies note that their sense of self alters as the devices aids them through rehabilitation programs and increase their confidence. Individuals with spinal cord injury who participated in a study on the use of robotic Locomotor exoskeletons expressed that their experience of being able to walk with the aid of the device led to hope for the prospect of regaining their ability to walk routinely (Kinnett-Hopkins et al., 2020). While the study reported on the positive implications of exoskeletons, it failed to address the psychological impacts exoskeletons have on patients. A study on assistive devices for decreased arm function concluded that, “the balance between the functional benefit of a device and the burden of use is still not ideal. No device will be as efficient as the healthy human arm, but it seems there is still potential for improving this balance” (Heide et al., 2014, p.12). For individuals using daily assistive exoskeleton devices, successful achievement of enhance mobility does not complete well compare to a healthy muscle and may result in rejection of exoskeletons. For rehabilitation purposes though, this issue is not prominent. Instead, frustration mainly comes from the restrictive nature of exoskeletons and disappointment that the technology did not meet their expectations that were formed from engineers advertising a reassuring and promising solution. Despite reporting these difficulties and negative elements, a study on robotic-assisted gait training (RAGT) devices reported that participants “considered RAGT as useful and beneficial and would choose to add RAGT to their rehabilitation programme, if given the choice (McDonald et al., 2022, p. 7). This finding indicates that the presence of exoskeletons still has an encouraging future in the medical sphere, but designs and promotions of their abilities by engineers and the healthcare system must be adjusted to maintain interest of the target population.

Conclusion

My capstone team will be designing an exoskeleton that is cost-effective and simple to use. The development of our device will hopefully allow exoskeleton rehabiltion to be more accessible and intituative to stroke patinets. Through addressing the frustrations of previous exoskeleton designs, there is a possibility that the chance of exoskeleton reahbilition will be better accepted by those seeking out way to improve their muscle function after a stroke. My STS research focuses on how influence of interaction between various social groups and the exoskeletons have on the design development of exoskeletons. Learning from their responses, I will be able to mindfully present a design that will produce a exoskeleton that decreases the limitations of exosekelton adoption in the medical sphere.

References

Chen, C.-T., Lien, W.-Y., Chen, C.-T., Twu, M.-J., & Wu, Y.-C. (2020). Dynamic modeling and motion control of a cable-driven robotic exoskeleton with pneumatic artificial muscle actuators. *IEEE Access*, *8*, 149796–149807. https://doi.org/10.1109/ACCESS.2020.3016726

Gandolla, M., Dalla Gasperina, S., Longatelli, V., Manti, A., Aquilante, L., D'Angelo, M. G., Biffi, E., Diella, E., Molteni, F., Rossini, M., Gföhler, M., Puchinger, M., Bocciolone, M., Braghin, F., & Pedrocchi, A. (2021). An assistive upper-limb exoskeleton controlled by multi-modal interfaces for severely impaired patients: Development and experimental assessment. *Robotics and Autonomous Systems*, *143*, 103822. https://doi.org/10.1016/j.robot.2021.103822

Greenbaum, D. (2015). *Ethical, legal and social concerns relating to exoskeletons* [SSRN Scholarly Paper]. https://papers.ssrn.com/abstract=2843109

Janssen, M. M. H. P., Lobo-Prat, J., Bergsma, A., Vroom, E., & workshop participants. (2019). 2nd Workshop on upper-extremity assistive technology for people with Duchenne: Effectiveness and usability of arm supports Irvine, USA, 22nd-23rd January 2018. *Neuromuscular Disorders: NMD*, *29*(8), 651–656. https://doi.org/10.1016/j.nmd.2019.07.005

Kinnett-Hopkins, D., Mummidisetty, C. K., Ehrlich-Jones, L., Crown, D., Bond, R. A., Applebaum, M. H., Jayaraman, A., Furbish, C., Forrest, G., Field-Fote, E., & Heinemann, A. W. (2020). Users with spinal cord injury experience of robotic Locomotor exoskeletons: A qualitative study of the benefits, limitations, and recommendations. *Journal of NeuroEngineering and Rehabilitation*, *17*(1), 124. https://doi.org/10.1186/s12984-020-00752-9

Lo, A. C., Guarino, P. D., Richards, L. G., Haselkorn, J. K., Wittenberg, G. F., Federman, D. G., Ringer, R. J., Wagner, T. H., Krebs, H. I., Volpe, B. T., Bever, C. T., Bravata, D. M., Duncan, P. W., Corn, B. H., Maffucci, A. D., Nadeau, S. E., Conroy, S. S., Powell, J. M., Huang, G. D., & Peduzzi, P. (2010). Robot-assisted therapy for long-term upper-limb impairment after stroke. *The New England Journal of Medicine*, *362*(19), 1772–1783. https://doi.org/10.1056/NEJMoa0911341

Maciejasz, P., Eschweiler, J., Gerlach-Hahn, K., Jansen-Troy, A., & Leonhardt, S. (2014). A survey on robotic devices for upper limb rehabilitation. *Journal of Neuroengineering and Rehabilitation*, *11*, 3. https://doi.org/10.1186/1743-0003-11-3

McDonald, C., Fingleton, C., Murphy, S., & Lennon, O. (2022). Stroke survivor perceptions of using an exoskeleton during acute gait rehabilitation. *Scientific Reports*, *12*(1), 14185. https://doi.org/10.1038/s41598-022-18188-7

Van der Heide, L. A., van Ninhuijs, B., Bergsma, A., Gelderblom, G. J., van der Pijl, D. J., & de Witte, L. P. (2014). An overview and categorization of dynamic arm supports for people with decreased arm function. *Prosthetics & Orthotics International*, *38*(4), 287–302. https://doi.org/10.1177/0309364613498538

Wolff, J., Parker, C., Borisoff, J., Mortenson, W. B., & Mattie, J. (2014). A survey of stakeholder perspectives on exoskeleton technology. *Journal of NeuroEngineering and Rehabilitation*, *11*(1), 169. https://doi.org/10.1186/1743-0003-11-169