Design of an Upper-Limb Exoskeleton for Stroke Rehabilitation

Analysis of Societal Impact of Exoskeletons for Personal Use

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By
Carly Thurman

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Technical Team Members:
Madison DePierro, Alex Parson, Samantha Nicholson, Joel Val, Abby Kong, Caleb Jung

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.

ADVISORS

Benjamin Laugelli, Department of Engineering and Society

Sarah Sun, Department of Mechanical Engineering

Introduction:

The increasing usage of exoskeletons for paralysis to provide a ‘solution’ for the disability is driving an important necessity to understand when the implementation of exoskeletons should be acceptable. An exoskeleton is a mechanical system comprised of three main features: actuators, sensors, and controllers. Sensors receive information about the environment; controllers take the sensor data and send a command to the actuator, which converts the signal from the controller into mechanical motion. Robotic exoskeletons play an important role in a rehabilitation facility to provide numerous benefits to the paralyzed community including partial or full motor recovery. There are lower-limb, upper-limb, and whole-body exoskeletons used for various forms of paralysis and muscle weakness. The most common causes of paralysis are a stroke, spinal cord injury (SCI), or neurological disorder (Armour, Courtney-Long, Fox, Fredine, & Cahill, 2016). The technical design described below outlines a possible exoskeleton that serves the purpose of stroke rehabilitation to regain mobility.

It is also important to address the social factors and biases of exoskeleton designs to fully understand the implication the design has on society and will be considered in the STS section of this paper. The perpetual nature of ableism that is inherent to exoskeleton designs is also examined below, specifically addressing exoskeleton designs for SCIs. It is important to determine the reasoning behind the design of an exoskeleton to not inadvertently further ableist biases within society. The implementation of exoskeletons in personal settings highlights a complex issue that by only focusing on a technical design without determining why the technology was created, it can inadvertently create an ableist environment.

Overall, medical exoskeletons are extremely beneficial in assisting the recovery of muscle weakness and paralysis, yet they are inherently sociotechnical. Therefore, in order to determine when it is appropriate to design an exoskeleton, the technical aspects and social implications must be evaluated. The technical project listed below highlights the medical benefits exoskeletons may provide to patients while attempting to further develop current exoskeleton designs, while the STS project details the cruciality of understanding the social implications that arise when exoskeletons are no longer used in a rehabilitative context.

Technical Project Proposal:

Strokes are caused by severely reduced blood flow in a blood vessel within the brain, or if a blood vessel in the brain ruptures (Mayo Foundation for Medical Education and Research, 2022). It may result in any number of complications with the predominant indicator being weakness or paralysis, which "may affect all muscle groups of the upper limb, or may be selective, affecting some muscle groups more than others" (Raghavan, 2015, Learned Nonuse). A helpful rehabilitative therapy for a patient suffering from weakness or paralysis due to a stroke is a mechanical exoskeleton. Upper-limb exoskeletons most commonly provide repetitive and task-specific movements, which "mak[es] effective use of neuroplasticity for functional recovery in neurological patients" (Ambrosini, Dall-Gasperina, Gandolla, & Pedrocchi, 2019, Abstract).

Exoskeletons vary in complexity. Mechanically, the degrees of freedom, weight, joint connection, and type of actuator may all vary based on the designer. Computationally, the type of control (closed or open loop feedback) may vary based on the rehabilitation needs of the patient. Realistic motions require more actuators and complex calculations to ensure the exoskeleton functions properly; however, these features greatly increase the price to average around $130,000 (Palazzi et al., 2022, Introduction). This pricing can omit a large population that does not have health care to receive the treatment that would greatly assist in their recovery.

Upper-limb exoskeletons are extremely useful in regaining motor abilities, "however, existing exoskeletons tend to be expensive and only available for a few people" (Palazzi et al., 2022, Abstract). While the technical design proposed below does not offer advanced technology in rotational motion or full independence for the user, it does address and attempts to mitigate the high-cost nature that exoskeletons currently exist within.

The technical design of the upper-limb exoskeleton will consist of a much cheaper alternative than the current market offers: 3D printed materials. The design will further lower the cost by reducing the number of actuated joints and providing four degrees of freedom rather than six: flexion/extension of the shoulder and elbow joints, abduction/adduction of the shoulder joint, as well as lateral/medial rotation of the shoulder (Figure I). This design will greatly reduce the cost because the number of actuators is less, and yet this exoskeleton will still allow the patient a general range of motion that can begin to reform neuropathways that were disrupted due to stroke. Because the exoskeleton will consist of 3D printed materials rather than metals, the overall weight will also be reduced.

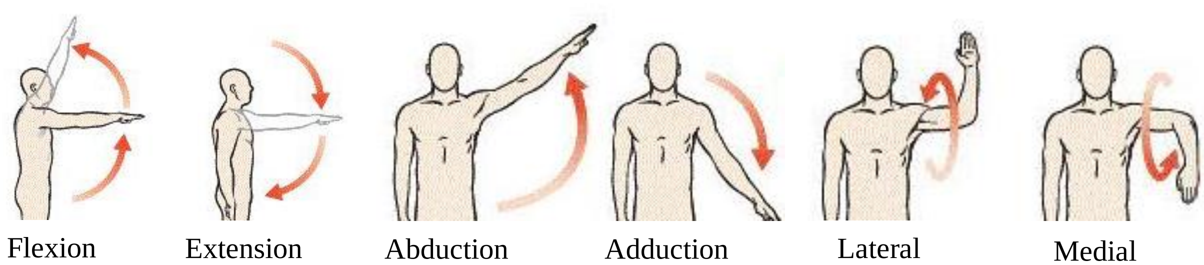

Figure I: Mobility Degrees of Freedom for the Body

Prototypes for the upper-limb exoskeleton design will be created in computer-aided design (CAD) software. Individual parts may be constructed and then assembled within the CAD software, which will allow the exoskeleton to be virtually configured. Force simulations will also be performed on the assembled exoskeleton to experiment with the strength and design before the product is 3D printed. Upon printing the exoskeleton and joining the actuators to simulate the degrees of freedom, the range of motion can be tested. The exoskeleton's motion capacity will be limited by the average range of motion for the shoulder and elbow joints respectively and will have the overall goal of repetitive movements. When the product is deemed to provide an adequate and desired range of motion for a potential patient, the upper-limb exoskeleton will be tested with a human user to ensure the design is operational.

The technical project's design cost will be estimated based on the price of the 3D printed parts as well as the actuators. Then that cost will be compared to other exoskeletons currently being marketed to hospitals and rehabilitation facilities. A low-cost exoskeleton is extremely important to the progression toward accessible rehabilitation treatments for all income levels.

STS Project Proposal:

Exoskeletons provide a multitude of benefits that range from rehabilitation assistance to psychological improvements in paralyzed patients (Gardner, Potgieter, & Noble, 2017). For patients that have suffered an SCI that led to paralysis, there is a lower-limb exoskeleton being marketed to provide mobility for personal use; it is known as the Rewalk-P exoskeleton (Rewalk, 2021). The technology initiates a walking motion by detecting "minor trunk motions and changes in center of gravity", while the "software algorithm analyzes inputs from the sensor and generates pre-set hip and knee movements in alternating legs that result in stepping. Crutches are required to provide stability" (Canada Drug and Health Technology Agency, 2021). The overall goal of the Rewalk design is to allow someone who has sustained an SCI to regain the use of their legs, at least through simulation, so that they may be able to move around in a manner to which they were once accustomed. While it may seem that the at-home Rewalk exoskeleton is an incredible first step in attempting to help those who live with paraplegia, it is imperative to understand the reasoning behind the design, because an at-home exoskeleton may inherently perpetuate ableism throughout communities and enforce a power dynamic insinuating that able-bodied individuals provide more value to communities.

The social implications of a personal exoskeleton are much more consequential than they may initially seem. The Rewalk exoskeleton seems to portray the idea that someone who suffers from paralysis will have the ultimate goal of regaining the ability to walk and assimilating back into the community. If the future development of exoskeletons follows this implicit ideology, designers will inherently diminish the societal worth of those who are paralyzed. This current design approaches paralysis by "viewing it as a problem that exists in a person's body. As a consequence, that individual is thought to require treatment to approximate normal functioning", even if the individual is otherwise considered healthy (Goering, 2015). A person can be physically and medically stable whether in a wheelchair or not; yet the designers of Rewalk attempt to provide a healthy individual that has paraplegia a way to walk, because it is a 'problem' to not have complete mobility. SCI patients have become "marginalized from defining their own wishes" due to a multitude of engineers and designers "replicating th[e] same top-down assumptions about what people [with disabilities] want" (Eveleth, 2015).

Examining the Rewalk exoskeleton through the lens of technological politics shows that while the technological design may provide benefits, the societal impact overall marginalizes anyone that suffers from paralysis. Technological politics pertains to the idea that technology holds political power and that devices may possess the ability to grant specific groups greater power over others (Winner, 2017, p. 127). Designers can drive a greater disparity between different groups, whether inadvertently or intentionally. In the case of the Rewalk exoskeleton, the design encourages social power and influence to reside in able-bodied individuals, or appearing able-bodied, by implying the ideal lifestyle that everyone should strive for. Furthermore, introducing exoskeletons as personal devices discourages organizations from creating accessibility-friendly environments which invalidate a group of the population that has come to accept paralysis as a part of their identity.

While the Rewalk is an amazing feat of technology, it ultimately drives a power dynamic between able-bodied and disabled individuals. The exoskeleton does not provide a more time-efficient form of transportation; it may only be used to walk on smooth and level terrain at a slow pace (Gardner et al., 2017). Furthermore, the cost alone of one Rewalk exoskeleton is over $70,000 and the lifespan is indicated to last for 5 years on average (Canada's Drug and Health Technology Agency, 2021). The ultimate intent of the Rewalk exoskeleton is to offer paraplegics a way to walk again, even if it is not the most beneficial to the user, simply because the community that uses wheelchairs or other mobility assistive devices is often marginalized to only their visible disability. It is important to question "why many people seem more interested in hoisting someone out of their wheelchair than they are in making spaces accessible to that chair" (Eveleth, 2015).

Rather than follow the ableist biases that are embedded in the Rewalk design, technology could be used to assist SCI injuries by developing solutions to pressure sores, urinary tract infections, or circulatory disorders, all of which are common complications of paraplegia (SpinalCord.com Team, 2021, Living with Paraplegia). Furthermore, a "growing number of companies are developing assistive technologies to help disabled people walk – but these devices can distract from infrastructure changes that would make cities more disability-friendly"

(Eveleth, 2015). When Marilyn Golden, a senior policy analyst at the Disability Rights Education and Defense Fund, was asked specifically about the Rewalk exoskeleton, she felt that "the key distinction is changing society [rather than] changing the individual with a disability" (Eveleth, 2015). Personal exoskeletons attempt to force assimilation of a specific community rather than try to accommodate a different lifestyle, which inherently drives an imbalance in power and worth between the two distinct groups.

Conclusion:

The technical project described above will deliver a low-cost rehabilitative exoskeleton design that will assist stroke patients that suffer from muscle weakness or paralysis in upper limbs. The STS project will analyze ways in which technological politics play a role in personal exoskeleton design and whether those designs intentionally or inadvertently drive biases and power dynamics in society. The implications of design addressed in the STS project will affect the design methods of the technical project by ensuring the design does not inherently further ableist biases but rather attempt to provide rehabilitative services that would allow recovery of 8 mobility. The culmination of both projects addresses the sociotechnical challenge to understand the implementation of exoskeletons to aid with paralysis: The technical project shows a way in which a rehabilitative exoskeleton can be used, and the STS project researches the potential negative societal impacts personal exoskeletons may have on the paraplegic community.

Word count: 1967

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