Upper Limb Exoskeleton for Shoulder Joint Control
(Technical Paper)

A Double-Edged Sword: How the Prosthetics Industry Perpetuates Mental Health Disorders
(STS Paper)

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Mechanical Engineering

By
Nazirah Farach Rojo

November 1, 2021

Technical Team Members:

Colton Applegate
Joseph Carley
Nazirah Farach Rojo
Marvin Lee
Isabella Nazari

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

Bryn E. Seabrook, Department of Engineering and Society

Sarah Sun, Department of Mechanical and Aerospace Engineering

Introduction

Millions of people live with movement disorders, for example, in the US close to one million people live with Parkinson's. Neuromuscular disorders (NMD) can be treated with physical rehabilitation, however, in a daily basis patients need help with their normal activities, for which prosthetics can become essential. Prosthetics are divided into two subgroups: exoskeleton (outside structure) and endoskeleton (inside structure and covered with prosthetic foam) prosthetics. Exoskeletal prostheses are more commonly used and can also be used as rehabilitation tools. These wearable robotic designs are created to help patients get their mobility back after an injury and other are meant to work as a prosthetic limb in case of amputation or complete control loss. The design and manufacturing of these devices can become extremely expensive especially for children because they need new fitted prosthetics more often than adults. For example, a prosthetic leg can cost anywhere from $5,000.00 to $50,000.00 on average, and for the average child the prosthetic needs to be changed every six to twelve months (Seager, 2012). This cost can create an extreme amount of stress and negative psychological side effects on the caregivers of the children, and the children themselves.

There are about 3.6 million babies born in the US per year (Thompson, 2021). For every 1.9 thousand babies born, one has congenital limb differences (Centers for Disease Control and Prevention, 2020). Using algebra one can show that approximately 1900 babies are born with limb differences in the U.S. per year. These kids face many psychological problems, ranging anywhere from body image, phantom leg, depression to anxiety, however there are not many studies that show these or other psychological effects of having traumatic nor congenital limb differences in children. Another component to take into consideration of this specific group of children is insurance. In a medical news article written January 2021 it is specified that most

families have to at least pay for about 20% of the prosthetic device if they have Medicare (Ledbetter, 2021). These facts demonstrate the large financial need children with limb differences have, and the need for better and more affordable prosthetics to be engineered.

The technical capstone's goal is to build an exoskeleton arm with soft robotics. Soft robotics are robotics using soft materials, using more flexible materials like thermoplastic polyurethane and wires (WhatNext, 2021). Soft robotics are more comfortable to wear and to get used to because they resemble the human body more in how they feel and how they look. The science technology and society research is focused in relation to the psychological effects of limb differences in children and prosthetics. These two relate in that they are both designed to enhance people's lives, but their psychological effect on the users and their family are not always thought of in the design process.

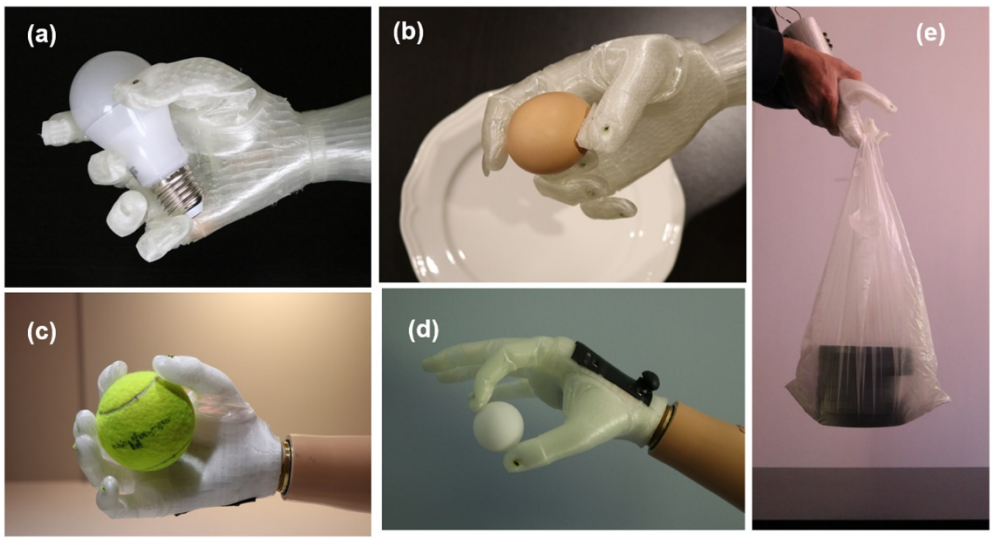

Figure 1.- From a research article which focused on 3D printing soft prostheses and using cables through the fingers for mobility (Mohammid, 2020).

Wearable Electronics and Robotics Design

The arm is a powerful tool for the human race, taking into account the seven degrees of freedom (DoF) of the arm, including the shoulder, elbow, and wrist joints (Hyunchul, 2012). The

upper body is essential for the everyday life, from eating, to driving, arms are an incredible source of power, balance and precision. Exoskeleton prosthetics are wearable robotic devices that are used mainly for rehabilitation. The Capstone Wearable electronics and Robotics Design is mean to design a soft exoskeleton prosthetic to help people who have had arm injuries regain their strength through rehabilitation.

A study determined that there were a total of about 18,000 spinal cord injuries recorded in the US alone in 2020. These injuries often cause gait impairment, which is why during the recovery process learning how to walk again is one of the biggest priorities during rehabilitation. Exoskeletal prosthetics are perfect for rehabilitation because they provide support around the person and helps them by re-introducing the correct manner of walking to help recover and increase muscle strength. Usually after traumatic accidents or long surgeries patients have to be in bedrest or keep the injured part of their body in a cast, which meant that their muscles are not being used as they used to and therefore get weaker. Conventional rehabilitation usually includes exercises such as walking with partial weight support. This part of rehab is extremely difficult not only for the patient but also for the physiotherapists. Exoskeleton robotics help with the rehabilitation process because they are a safe and dependable physical interaction for both the patient and physiotherapists. Exoskeleton and exosuits are mechanical enhancements that have been proven to reduce workload for users (Lessard, Pansodtee, Robbins, Trombadore, Kurniawan, & Teodorescu, 2018).

The capstone project is to design a wearable upper limb exoskeleton that integrates wearable electronics, pneumatic actuators, and feedback control as human assistive technology. There are 3 teams working together, one is working on the electronic circuit design, the second team is working on the mechanical design of the shoulder and bicep, and the third team is

working on the elbow joint and forearm. This design will be made using soft robotics, meaning that the circuit will be designed and sent to be printed on a cloth like sheet that will be attached to the arm and exoskeleton. This "sheet" will be connected to a MyoWare Muscle Sensor that have the capability of reading electromyography (EMG) data, which assesses the health of muscle and the motor neurons. This data is then transferred to the Exoskeleton to use the pneumatic actuator to contract or relax, depending on the data, to move and mimic what they user is doing to enhance the strength at which the movement is created.

One of the big design components of this mechatronic system is inverse kinematics, since there need to be several tests to come up with a code that if a certain data is obtained from the sensors, then it means that the user wants to move a point to a desired set of coordinates in the 3D plane. Inverse Kinematics is the study of motion, mainly used to establish a robot's desired position and motion using joint configuration (TheMathWorks, n.d.) has to be done thinking of both the elbow and end of the forearm as two coordinate points that need to move as the user moves. Figure 2 shows what one of the soft robotic materials is, this is a braided wire that is very flexible, soft and cheap. This project is very similar to the Sensing and Control of Multi-Joint Soft Wearable Robot for Upper-Limb Assistance and R0065habilitation design, although one of the main differences is the material being used, the circuitry and the mechanical exoskeleton design, however the concept of this capstone is very similar to it (Proietti, 2021.).

Figure 2.- This is an image of an expandable braided wire. When the volume inside of this wire, the wire contracts mimicking a flexed muscle by creating a pulling force.

This technical project will result in prototypes of EMG sensor design and actuator design that will be ready to test by the end of the term. The desired outcome is to have a complete mechanical and electronic prototype ready for iteration and improvements by the following semester. Once the final prototype has been completed an IBR approval will be required to conduct a survey on participants willing to try on the prototype and provide feedback for improvement. The final deliverable should be a upper-limb exoskeleton using soft robotics, such as pneumatic activators and artificial muscles that has the capability of supporting a patient with a neuromuscular disorder on their daily activities, as a form of aid and rehabilitation.

Psychological Effects of Limb Differences and Prosthetics on Children

Some studies have demonstrated that about 1 out of every 1900 babies are born with limb differences in the United States (Centers for Disease Control and Prevention, 2020). A study done in 2020 by the International Society of Prosthetics and Orthotics that shows that there are

about 14,000 children in the MarketScan database who had major lower limb loss out of the 36.5 million children in the database (Ledbetter, 2021). According the same study there is about 38 cases per 100,000 cases of insured children with this problem. This group can be broken down into 84% from congenital deficiencies and 13.5% from trauma (Ledbetter, 2021). Although there are not many in-depth studies on the effects of children needing a prosthetic limb, there are many components that affect people who belong to this group, whether it's congenital or post birth. One of the main challenges these kids face is finding a prosthetic that fits their necessities and capabilities. There are many different types of prosthetics out there, and these can be divided into two main sub-groups: functional and cosmetic. Not having prostheses that fit both these requirements hinders the metal state of many children as they grow up, especially those that need them after a traumatic experience.

Technological determinism (TD) is the concept that societal development is shaped by technology rather than the other way around (Smith, 1994) meaning that the limb different community is directly affected and shaped by the current availability of prosthetics, their capabilities and overall cost. In this case soft determinism is the one that best describes the situation because there is still human freedom that shapes the prosthetics but technology is mainly the one directly affecting the community. Prosthetics are a technology that need to adjust and adapt to the users, however, since the advancements that have been made are not widely approved by the different insurance companies, many of these technologies cannot be accessed by the people who need them. For example, soft robotics are an amazing advancement in the world of prosthetics but they are still being developed. Most of the research papers and projects done are with the help of current patients in need of prostheses, which is a way in which the

group can still affect this technology, but the technology itself and its capabilities are the ones that at the end determine the difficulties and burdens of this group.

The Atlas of Limb Prosthetics has a chapter on introducing a couple of the main difficulties this group faces. The first one being for children who have lost a limb after birth, these children usually go through a long grief episode before they start getting used to the idea that they will never be able to use that extremity like they used to. These children want to immediately go back to what their physical capabilities used to be, which is usually not possible given the fact that these children have to go through rehabilitation, including prosthetic fitting, physical therapy and counseling. On the other hand, children who have missed this limb from birth are not always eager to get fitted for a prosthetic, they do not feel like they have lost something when they are young and so they try to live their life as the other kids around them. Therefore, most prosthesis are not wanted many by kids for the mere reason of it being uncomfortable, or difficult to control. For example, if they have lived without this limb their whole life, they might never had had to use a specific set of muscles.

Prosthetics is a technology is as socially relevant as it is scientifically. In a technologically deterministic sense, there have been several innovations in prosthetics that have helped children participate in different social activities such as sports, playing music and participating in theater (Hall, 2020). Some critics of TD say that technology is socially determined, that as social structures evolve together, they are not deterministic and that the effects these technologies have depend on the social structure already established (Technological determinism, 2013).

Critics of TD argue variously that technology itself is socially determined, that technology and social structures co-evolve in a non-deterministic, emergent process, or that the

effects of any given technology depend mainly on how it is implemented which is in turn socially determined. Given the proliferation of new technologies in modern capitalism, the TD debate is continually renewed.

Research Question and Methods

This research will be conducted by a series of prosthetics article review, personal blogs, research papers, hospital journals, insurance company coverage information, and discourse analysis. Some of the main key words for this research paper are: prosthetics, prosthesis, psychology, upper limb, lower limb, limb differences, amputation, soft prosthetics, exoskeleton robotics, wearable electronics, phantom leg, and technical determinism. The purpose of this research paper is to have a better understanding of the psychological effects of limb differences in children and how prosthetics affect their lives. This research method aligns with the research question because there is a need for scholarly articles describing prosthetic devices

Conclusion

The technical capstone is on designing a wearable upper limb exoskeleton that enhances their mobility by mimicking their muscle as they flex and relax the muscle. The sensor of the nano board reads this and sends the data to the designed mechanical system the exoskeletal prosthetic will mimic this. After the semester is over and information from patients is obtained the prototype will be iterated until the best design is obtained with the time constrain. The main goal of the research paper is to have a better overview of the psychological effects of having limb differences in children and how the technology of prosthetics affects them psychologically in the day to day.

References

Centers for Disease Control and Prevention. (2020, October 26). *Facts about upper and lower limb reduction defects*. Upper and Lower Limb Reduction Defects. Retrieved October 20, 2021, from https://www.cdc.gov/ncbddd/birthdefects/ul-limbreductiondefects.html.

Hall, M., Cummings, D., Welling Jr., R., Kaleta, M., Koenig Jr., K., Laine, J., & Morgan, S. (2020). Essentials of Pediatric Prosthetics. *JPOSNA*, *2*(3). Retrieved from https://www.jposna.org/ojs/index.php/jposna/article/view/168

Hyunchul Kim, Miller, L. M., Byl, N., Abrams, G., & Rosen, J. (2012). Redundancy resolution of the human arm and an upper limb exoskeleton. IEEE Transactions on Biomedical Engineering, 59(6), 1770–1779. https://doi.org/10.1109/tbme.2012.2194489

Ledbetter, S. (2021, January 7). *Medicare and prosthetics: Coverage, restrictions, and costs*. Does Medicare cover prosthetics? Retrieved October 23, 2021, from https://www.medicalnewstoday.com/articles/does-medicare-cover-prosthetics#summary.

Lessard, S., Pansodtee, P., Robbins, A., Trombadore, J. M., Kurniawan, S., & Teodorescu, M. (2018). A Soft Exosuit for Flexible Upper-Extremity Rehabilitation. *IEEE transactions on neural systems and rehabilitation engineering : a publication of the IEEE Engineering in Medicine and Biology Society*, *26*(8), 1604–1617. https://doi.org/10.1109/TNSRE.2018.2854219

Marras, C., Beck, J. C., Bower, J. H., Roberts, E., Ritz, B., Ross, G. W., Abbott, R. D., Savica, R., Van Den Eeden, S. K., Willis, A. W., & Tanner, C. M. (2018). Prevalence of

parkinson’s disease across North America. Npj Parkinson's Disease, 4(1). https://doi.org/10.1038/s41531-018-0058-0

McLarney M;Pezzin LE;McGinley EL;Prosser L;Dillingham TR; (2021, April 1). *The prevalence of lower limb loss in children and associated costs of prosthetic devices: A national study of commercial insurance claims*. Prosthetics and orthotics international. Retrieved October 20, 2021, from https://pubmed.ncbi.nlm.nih.gov/33158398/.

Mohammadi, A., Lavranos, J., Zhou, H., Mutlu, R., Alici, G., Tan, Y., Choong, P., & Oetomo, D. (2020, May 14). *A practical 3D-printed soft robotic prosthetic hand with multi-articulating capabilities*. PLOS ONE. Retrieved October 20, 2021, from https://journals.plos.org/plosone/article?id=10.1371%2Fjournal.pone.0232766.

Proietti, T., O’Neill, C., Hohimer , C. J., Nuckols, K., Clarke, M. E., Zhou, Y. M., Lin, D. J., & Walsh, C. J. (2021, November 2). *Sensing and control of a multi-joint soft wearable robot ...* IEEE ROBOTICS AND AUTOMATION LETTERS. Retrieved October 22, 2021, from https://biodesign.seas.harvard.edu/files/biodesignlab/files/2021_proietti_ieee_ral_-_sensing_and_control_of_a_multi-joint_soft_wearable_robot_for_upper-limb_assistance_and_rehabilitation.pdf.

Seager, T., Selinger, E., & Wiek, A. (2012). Sustainable Engineering Science for Resolving Wicked Problems. *Journal of Agricultural and Environmental Ethics*, *25*(4), 467–484. https://doi.org/10.1007/s10806-011-9342-2

Smith, M.R. (1994). Technological Determinism in American Culture. *Does Technology Drive History?: The Dilemma of Technological Determinism*. (pp. 1-17). Cambridge, Massachusetts. London, England. The MIT Press.

Technological determinism: A Critique based on several readings in adult education. Learning Tech. (2013, October 25). Retrieved October 23, 2021, from https://sites.psu.edu/natalieharp/writings/technological-determinism-a-critique-based-on-several-readings-in-adult-education/.

TheMathWorks. (n.d.). What is inverse kinematics? What Is Inverse Kinematics? - MATLAB & Simulink. Retrieved November 20, 2021, from https://www.mathworks.com/discovery/inverse-kinematics.html.

Thompson, D. (2021, May 5). *U.S. Birth Rates Continue to Fall*. U.S. News. Retrieved October 20, 2021, from https://www.usnews.com/news/health-news/articles/2021-05-05/us-birth-rates-continue-to-fall.

WhatNext. (2021, January 28). Applications of soft robotics. Retrieved October 23, 2021, from https://www.whatnextglobal.com/post/applications-of-soft-robotics.