**Movement Impairments From A Social Perspective: How Assistive Movement Devices Impact Those With Motor Disability**

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

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Spring 2024

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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## I. INTRODUCTION

According to the National Library of Medicine the global impact of spinal cord injuries (SCI) with respect to the years lived with disability (YLD) and annual age-standardized years lived with disability (ASYR) was estimated to be about 6.2 million cases worldwide (Ding et al., 2022). In addition to this, about 76 in 100,000 people contribute to this statistic. SCI impacts more than 17,800 Americans each year, with an estimated 294,000 Americans concurrently experiencing such injuries (Lasfargues et al., 1995). According to the U.S. Department of Health and Human Services (2023), spinal injuries lead to a multitude of physical and neurological impairments such as paraplegia, quadriplegia, chronic pain, and respiration issues to name a few. Spinal cord injuries primarily hinder the motor functions of a person therefore minimizing or even removing the usage of their limbs to move and communicate with other people (Kuriakose, 2022).

Some spinal cord injuries have various impacts on a person depending on if the person is injured on a particular part of the spine. According to the National Institute of Health (2023), spinal injuries happening closer to the bottom of the spine closer to the T2 to S5 vertebrae result in paraplegia. Paraplegia as they define is considered the condition where people have lost feeling in or are not able to move the lower parts of their body where the most impacted regions of the body can be but are not limited to the chest, stomach, lips, legs, and feet. The Shepard Center (2024) also noted that the closer an SCI is to the skull or brain area the more “extensive is the curtailment of the body's ability to move and feel. If the lesion is low on the spine, say, in the sacral area, there will likely be a lack of feeling and movement in the thighs and lower parts of the legs, the feet, most of the external genital organs, and the anal area. But the person will be able to breathe freely and move his head, neck, arms, and hands. By contrast, someone with a broken neck may be almost completely incapacitated, even to the extent of requiring breathing assistance."

As a result of these injuries, there have been urgencies to regain and obtain ways of motor assistance for those suffering from any SCI that would benefit from an opportunity. Assistive technology is a field of engineering that aims to improve the quality of life of certain groups of people based on their needs by focusing on an aspect of their current life that needs more assistance than another part. One of the most important aspects of the impact of assistive technology is how society and politics perceive it. With this in mind, I ask the following question: How has assistive movement technology impacted those with physical limitations and how critical is the urgency for a new design research for individuals suffering from SCI? Understanding the urgent need for innovative design research, particularly for those with Spinal Cord Injuries (SCI), demands a comprehensive examination. By delving into a range of assistive technologies and examining case studies of existing systems within socio-technical frameworks, we can illuminate the multifaceted impact and nuanced challenges inherent in these technologies. From analysis of individual perceptions of self concerning an SCI, exploration of stigma surrounding people with SCI, and consideration of competency we can utilize the theories of the SCOT framework and Technological momentum to grasp a firmer idea of how to work with individuals suffering from SCI to better assist them in the future. Each system offers unique opportunities for enhancing user independence and societal integration, underscoring the critical importance of addressing control mechanisms and design considerations within specific contexts.

## II. ANALYSIS WITH STS FRAMEWORKS

Francis provided a discussion on a previous study researching how able-bodied people perceive disabled people with and without bionic devices (Francis, 2022). She asserted bionic assistive devices can lead to more positive perceptions by able-bodied individuals and that perhaps in the future the competency gap will be bridged between people with and without disabilities.

With respect to the sociotechnical aspects of how assistive technology impacts those with disabilities, Bijker and Pinch's framework becomes relevant in this case because one of their most important points from the Social Construction of Technology framework was the multidirectional model which implies that different groups of people perceive some set of technology differently from another group (Bijker & Pinch, 1987). Considering the case of quadriplegics, multiple groups of people solve the same problem to assess a new solution that could provide a benefit to quadriplegics in a newly perceived way be it with brainwaves or with magnetic fields.

Hughes closely aligns with Bijker with assistive technology because Hughes' main points are that technology is influenced to improve upon itself such that it is always being influenced by factors such as innovation, reverse salient, and competition. Assistive technology is impacted by these factors such that a reverse salient provides the initial push for innovation which in turn inspires more groups of people to try and compete for a new assistive technology to be the traditional device in the future (Hughes, 1987). Bijker and Pinch's SCOT framework in combination with Hughes' aspects of technological momentum complement each other by challenging new growth for how newfound considerations with technological development begin. Development, where the phase in which the social construction of technology becomes clear. This involves the acquisition of social, political, and economic aspects necessary for the survival of a system beyond the technical artifact.

The SCOT framework builds upon Hughes' approach to Development by falling in line with the aspect of on how there can be multiple different perspectives on how a group values a particular technology and its function such that it can inspire another aspect of Hughes' which is innovation. Innovation can be defined as building and improving on past technological developments to establish a new technological system. Innovation in terms of assistive movement systems can benefit an individual who may need a more sophisticated movement system than there is currently, but with innovation, instills a sense of competitiveness. Competition is present with innovation since multiple groups of system builders are eager to become the new relevant common practice for a particular technological system. All of these factors can positively impact the technological momentum of wheelchair development but there is an issue that was underscored while discussing the benefits of Hughes' approach and SCOT which is if we are considering how the individuals are using the technological system.

One derivative of assistive movement devices is wheelchair mobility systems. There are multiple types of mobility devices for wheelchair users such as wheelchairs that can be moved manually, simply by rotating the wheels that move it by hand. Another way is for older people who are not as strong as they were previously to use a motorized wheelchair for assistance in moving around now. This allows the user to have freedom of movement at an older age while not forcing them to depend on society to help them but still have their freedom of movement. Now considering the case where a handicapped user has needs where they are not able to move anything below their neck, we call this tetraplegia or quadriplegia. This is an uncommon case where a spinal cord injury about the neck severs a connection of the body so that the brain cannot interact with the other appendages of the body such as the arms or legs. While this case is rare, it still impacts millions of people, thus the comfort and freedom of movement for people with this diagnosis depend on society and engineers to develop new technology where they too can experience the freedom of movement without the worry of needing society to burden them. The most common way a person with this injury moves is through a sip and puff system where the user sends a series of sips and puffs for the movement device to decipher as a command of movement whether it be forward, rotate, back, or stop. The current technology that is commonly accepted as the traditional way for quadriplegics to move is the sip-and-puff method where a series of sips and puffs serve as data for a particular command for the wheelchair (Jeff, 2023), but new solutions are being created to compete with the traditional method. There have been several studies for those with manual wheelchairs and those with motorized wheelchairs, but there are fewer case studies of those with tetraplegia even though this assistive device is equally if not more important than the previous assistive technology devices. Manual wheelchairs have autonomy and control, while motorized wheelchairs provide for enhanced mobility. In contrast, the forefront of assistive movement devices with tetraplegics is competitive in a sense because the current system of use has issues where the user feels exhausted after an extended period of use due to using cheek muscles that are not regularly used for a long time (Menon et al., 2015). The reason why there is competition for finding a better mobility device practice is because while using the sip and puff systems the problem arises that the idea of sending sips and puffs in a moment where time is of the essence can be stressful and tedious. For example, needing to stop or adjust the motorized sip and puff system before the user falls off the side of a sidewalk demands the user to remember the command within a time frame that if failed could eject the user from the wheelchair and they would not be able to move and would require help from another person. Therefore, the urgency for new design research for individuals suffering from

SCI is critical, and multiple developments are taking place for those in need with these aspects of STS in mind.

## III. CASE STUDIES

The first sophisticated engineered device is from Izzuddin and his fellow researchers who used a system that uses an Electroencephalography (EEG) signal processing headset that reads electrical body signals and then classifies the signal into a movement command by using machine learning to objectively qualify the signal being sent to the system for the wheelchair (Izzuddin et al., 2015). A more recent application by research groups led by Lund and Lontis of providing a new solution to people suffering from tetraplegia is a tongue-driven system where the user takes advantage of the intricacies of how sophisticated the movement of the tongue is. Effectively, the tongue can be interpreted as a joystick where the user is able to use their tongue to send information to sensors to move a wheelchair in a direction they would like to move. This approach is more intuitive, which allows for the edge over inputting a series of sips and puffs to tell the wheelchair to move in a direction compared to simply moving the tongue forward to move forward. Researchers came up with using a magnet on the tongue to send data to a retainer in the mouth where the retainer would send information on how to move the wheelchair, essentially using the tongue as the joystick (Lund et al., 2010; Lontis et al., 2010). One of the benefits of this system is that a tongue-driven wheelchair has an easy learning curve and if very much more intuitive for those who have mobility impairments and those without, so both groups of people have the same learning rate. One of the difficulties with the system itself is that it is very user-centered, so it depends on the user to complete calibration protocols correctly for it to function as intended. In addition to calibration, processing speed is important, it needs to be fast enough where its not instantaneous but fast enough that it feels instantaneous, somewhere around 200 milliseconds at most which can be a difficult task to maintain for some wheelchair systems.

Similarly, Jain and Joshi wanted the system to focus on user comfort and be somewhat discreet to external observers, so they used an array of sensors that were external to the mouth that capture data which is processed by a microcontroller using a control algorithm that is then used to simulate a wheelchair in a program (Jain & Joshi, 2014). Wanting to focus on user feedback, technical, and social actors, Kim and Lu both focused on a voice-controlled assistive device project, which prioritized language inclusivity and explored facial movements for control (Lu & Chen, 2012; Kim et al., 2013). This research highlighted the significance of user feedback in designing assistive devices that improve mobility and minimize social challenges. Although both Hain, Joshi, and Izzuddin provided a system solution that is able to benefit individuals with SCI, perhaps the most revolutionary way to help assist users with SCI was recently developed through a company called Neuralink.

Neuralink announced in early 2024 that they had successfully implanted a brain-computer interface (BCI) into a human (Guarino, 2024). This success opens up a new window in assistive technology because it can find a perfect compromise between usability and user preferences in terms of facial visibility for a user. If the success at Neuralink is continued it is possible that the competency gap between able-bodied people and disabled people can be fully bridged, resulting in public perception of disabled people as being on the same level as able-bodied people. While Neuralink's breakthrough holds immense promise for advancing assistive technology and promoting inclusivity, it also prompts profound philosophical reflections on the nature of human identity and the intersection of biology and technology. In terms of the user's sense of self with Neuralink it is possible that the user could feel split between who they are as a person and who they are as a machine but, it is also possible that the user could consider the BCI an extension of their thought which would help the individual obtain and maintain their image and sense of self.

## IV. FURTHER ANALYSIS

In terms of the social impacts of assistive mobility devices, especially those with tetraplegia, the impact is significant. These devices play a pivotal role in establishing a sense of independence freedom and inclusion within our society. Manual and motorized wheelchairs have served as major stepping stones to including the lives of individuals with motor impairments by allowing them the freedom to contribute to society individually. Having the means to be able to contribute individually to society more it allows for more interconnectedness between those who do not have motor impairments and those with motor impairments. Despite these advancements, however, challenges do persist as seen with individuals with tetraplegia. This motor inhibition is a new challenge that can pose an issue to individuals who are looking to have freedom of movement and independence. For example, as seen above with sip and puff systems it is crucial that we accommodate for fatigue and speed of movement processes since movement is a very quick and dynamic process. These two simple freedoms truly underscore the need for continued innovation in assistive technology.

Assistive movement has a promising future, with the development of multiple new systems to use this brings about competition, and competition brings about innovation. By furthering advancements in technologies such as sensors and signal processing we would be honing in more refined and intricate systems that are more responsive and positively impact a user. These innovations offer increased independence, mobility, and inclusion within society. While traditional methods like sip-and-puff systems have been the norm, newer solutions like tongue-driven systems provide a more intuitive and less physically demanding alternative. However, challenges such as fatigue, calibration requirements, and processing speed persist, underscoring the ongoing need for innovation and user-centered design in assistive technology. Collaborative efforts between engineers, stakeholders, and users are crucial in driving the future of these innovations and ensuring inclusivity and accessibility in society. I believe that one of the most important features comes from the actual user of products, so placing more emphasis on user-centered designs and customization in the development of assistive mobility devices will only help tailor a better solution for individual needs and preferences which in turn would maximize individual satisfaction and contribution to society. By simply working with multiple parties and individuals who will be using these devices we can contribute to the evolving needs of individuals with mobility impairments by bridging the gap between inclusivity and accessibility in today's society with people with and without mobility impairments.

## V. CONCLUSION

As we have seen from Francis' study people have a particular social stigmatization and stereotyping for those with a disability. Although groups of engineers have been working to help bridge the competency gap created by those without disabilities and those with disabilities, there are still discriminatory practices in aspects of life, especially employment opportunities and access to public spaces (Barnes, 1992). Economic accessibility is also another prevalent issue for those suffering from SCI. This is because an SCI causes significant damage to important motor functions in the individual's body, as a result, to accommodate for the injury to adjust with new assistive movement devices it becomes costly to the extent that economic accessibility could be a driving force for what is withholding accessibility from individuals who need these devices to feel the same freedoms as an individual with no motor inhibitions (Barnes, 1992). Social isolation and loneliness also have impacts on individuals with SCI. Since individuals with SCI suffer from motor inhibition it is entirely possible that even though they may have an assistive movement device to bridge the competency gap, they could still struggle to fully participate in social activities and maintain meaningful relationships due to physical barriers and societal attitudes. Recognizing and addressing intersectionality is essential for promoting equity and inclusion within society and ensuring that individuals with SCI have equal opportunities to participate fully in all aspects of life. This requires adopting an intersectional approach to policy-making, advocacy, and service provision that considers the diverse identities and experiences of individuals with disabilities. Additionally, fostering collaboration between disability rights organizations, social justice advocates, and other marginalized communities is essential for advancing intersectional perspectives and dismantling intersecting forms of discrimination and oppression.

People with physical limitations, especially quadriplegics, need more user-friendly, discreet, and affordable assistive technology solutions. Traditional methods are often challenging and limit the independence of the impacted user. The impacts of the solution in mind from my capstone will hope to enhance the level of independence of a user as well as making it more inclusive and affordable by all people so that everyone is able to have their own mobile independence and freedom regardless of physical limitations. Being able to address the relevant assistive technology limitations can result in increased positive perceptions of society on those with disabilities. This paper aims to address or at least shed light on the relevant factors that shape the multifaceted relationship between assistive technology, the individual, and society with hopes that lead to a more inclusive and empowering future for those with disabilities.

## References

Barnes, C. (1992), "Disability and Employment", Personnel Review, Vol. 21 No. 6, pp. 55-73. https://doi.org/10.1108/00483489210021080

Bijker, W. E., & Pinch, T. J. (1987). The social construction of fact and artifacts. *Philosophy of technology: the technological condition: an anthology, 107-139.*

Cleveland Clinic medical. (2022). *Quadriplegia (tetraplegia): Definition, causes & types*. Quadriplegia. https://my.clevelandclinic.org/health/symptoms/23974-quadriplegia-tetraplegia

Ding, W., Hu, S., Wang, P., Kang, H., Peng, R., Dong, Y., & Li, F. (2022). Spinal cord injury: The global incidence, prevalence, and disability from the global burden of disease study 2019. *Spine*, *47*(21), 1532.

Francis, N. (2022). *Novel EMG-IMU Sensor Array for a 5-DOF Wearable Robotic Upper-Limb Exoskeleton; Examining the Politics Surrounding Assistive Devices*. Charlottesville, VA: University of Virginia, School of Engineering and Applied Science, BS (Bachelor of Science). https://doi.org/10.18130/0fb2-bb76.

Guarino, B. (2024, February 20). Elon Musk's Neuralink has implanted its first chip in a human brain. what's next? Scientific American. https://www.scientificamerican.com/article/elon-musks-neuralink-has-implanted-its-first-chip-in-a-human-brain-whats-next/#:~:text=Elon%20Musk's%20brain%20science%20start,human%20for%20the%20first%20time.&text=Billionaire%20technologist%20Elon%20Musk%20announced,human%20for%20the%20first%20time.

Izzuddin, T. A., Ariffin, M. A., Bohari, Z. H., Ghazali, R., & Jali, M. H. (2015, November). Movement intention detection using neural network for quadriplegic assistive machine.

In *2015 IEEE International Conference on Control System, Computing and Engineering (ICCSCE)* (pp. 275-280). IEEE.

Jafar, M. R., & Nagesh, D. S. (2023). Literature review on assistive devices available for quadriplegic people: Indian context. *Disability and Rehabilitation: Assistive Technology*, *18*(6), 929-941.

Jain, M., & Joshi, H. (2014). Tongue Operated Wheelchair for Physically Disabled People. *International Journal of Latest Trends in Engineering and Technology (IJLTET)*, *4*.

Jeff. (2023, April 28). *Understanding assistive technologies: What are SIP-and-puff systems?*. WCAG Audits, ADA Accessibility Audits & Section 508 Audits. https://www.boia.org/blog/understanding-assistive-technologies-what-are-sip-and-puff-systems#:~:text=The%20system.

Hughes, T. P. (1987). The evolution of large technological systems. *The social construction of technological systems: New directions in the sociology and history of technology*, *82*, 51-82.

Kim, J., Park, H., Bruce, J., Sutton, E., Rowles, D., Pucci, D., ... & Ghovanloo, M. (2013). The tongue enables computer and wheelchair control for people with spinal cord injury. *Science translational medicine*, *5*(213).

Kuriakose, D. C. & SpinalCord.com Team, & (2022). *Quadriplegia & Tetraplegia: Definition, causes, symptoms, and treatment*. Quadriplegia & Tetraplegia: Definition, Causes, Symptoms, and Treatment. https://www.spinalcord.com/quadriplegia-tetraplegia.

Lasfargues, J. E., Custis, D., Morrone, F., & Nguyen, T. (1995). A model for estimating spinal cord injury prevalence in the United States. *Spinal Cord*, *33*(2), 62-68.

Latour, B. (1992). Where are the missing masses? The sociology of a few mundane artifacts. *Shaping technology/building society: Studies in sociotechnical change, 1, 225-258.*

Lontis, E. R., Bentsen, B., Gaihede, M., Biering-Sørensen, F., & Struijk, L. N. A. (2021). Wheelchair control with inductive intra-oral tongue interface for individuals with tetraplegia. *IEEE Sensors Journal*, *21*(20), 22878-22890.

Lu, Y., & Chen, Y. (2012). Prototyping potential control systems to assist complete quadriplegics. In *The 5th 2012 Biomedical Engineering International Conference* (pp. 1-5). IEEE.

Lund, M. E., Christiensen, H. V., Caltenco, H. A., Lontis, E. R., Bentsen, B., & Struijk, L. N. A. (2010). Inductive tongue control of powered wheelchairs. In *2010 Annual International Conference of the IEEE Engineering in Medicine and Biology* (pp. 3361-3364). IEEE.

Menon, S., Nambiar, A., Pariyarathu, A., & Krishnamoorthy, M. (2015). Tongue Driven System. *International Journal of Engineering and Technical Research, 3(4). ISSN: 2321-0869.*

National Institute of Mental Health. (2022). *About Spinal Cord Injury*. U.S. Department of Health and Human Services, National Institutes of Health. https://www.nichd.nih.gov/health/topics/spinalinjury/conditioninfo#:~:text=The%20state%20of%20an%20individual,can%20usually%20be%20called%20paraplegic.

Newsome | Melton (2019). *Quadriplegia: Types of paralysis: Brain and Spinal Cord Injury Information*. Newsome | Melton. https://www.brainandspinalcord.org/quadriplegia/#:~:text=A%20patient%20with%20complete%20quadriplegia,control%20over%20their%20hand%20movements.

Shepherd Center, KPKinteractive, American Trauma Society, National Spinal Cord Injury Association, & Christopher & Dana Reeve Foundation. Levels of Injury. https://www.spinalinjury101.org/details/levels-of-injury.

Star, S. L. (1999). The ethnography of infrastructure. *American behavioral scientist, 43(3), 377-391.*

U.S. Department of Health and Human Services. (2023). *Spinal Cord Injury*. National Institute of Neurological Disorders and Stroke. https://www.ninds.nih.gov/health-information/disorders/spinal-cord-injury