Effect of User Groups on Co-Production Cycle of Wearable Exoskeleton Technology

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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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Abstract

The wearable robotic exoskeleton industry continues to grow with the needs of user groups increasing. The primary function of a wearable robotic exoskeleton is to enhance the mobility of its user, therefore the user should be present during its design to ensure it meets their needs. In this paper the three philosophies of technology will be used to analyze the effect of user groups' needs on the co-production cycle of wearable robotic exoskeleton technology. User groups play a major role in the success of the technology and push its progress to meet their needs. Currently, functionality of the device to complete daily tasks and the physical comfortability of the user are the biggest factors affecting engineer's designs. However, in order for more designs to be accepted by user groups, all aspects of users' needs have to be accounted for, including social and ethical concerns. Including users throughout the whole design process will ensure that more users accept wearable robotic exoskeletons.

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Introduction

When given the chance to choose which senior final project I would be a part of, I was immediately drawn to designing a Wearable Robotic Exoskeleton (WRE). The first thought I had when learning about this project, is that it sounded a lot like the Iron Patriot suit Tony Stark redesigned for Colonel James "Rhodey" Rhodes when he was paralized from the waist down so that he could regain mobility in his legs. I liked that I could be a part of a project that had the potential to directly help others. I felt that extending the topic to my STS Thesis would benefit me in how I approached my capstone. The question that drives my research is, With the commercialization of wearable exoskeleton technology, how will the needs of user groups affect the co-production cycle of this technology?

Wearable robotic exoskeletons (WRE) will provide those with muscular disorders with the means to regain at least part of their independence and allow them to perform daily tasks with more ease. Wearable robotic exoskeletons are designed to meet the physical needs of the user, with the primary goal of granting them enhanced mobility. The designs of WREs must be structured to meet the needs of user groups while taking into account that the user must be comfortable both physically and mentally. There needs to be guidance and regulation for the design and implementation of WREs; not just for technical and safety aspects, but for personal, interpersonal, and broader societal effects as well (Kapeller et al., 2020). How users interact with society will be greatly impacted by this technology, so in turn user groups should have a great effect on the co-production cycle of wearable exoskeleton technology. The co-production cycle refers to the cycle that society and technology are interlocked with each other in (Harbers, 2005). Technology pushes the progress of society, while society encourages the enhancement of technology to meet its demands. Society and technology are internally related and they need one another to progress (Harbers, 2005). The development of WREs is an ever changing cycle. The field of wearable robotic technology is increasing rapidly and it is predicted that the market size will be USD 4.2 billion by the year 2027 (Kapeller et al., 2020). Commercialization of this technology could lead to more demand by a growing population thus increasing the need for a more user-based design. There is also the possibility that the technology is not adopted because of rejection by the user groups if their needs are not completely met.

The purpose of this research is to analyze the roles that user groups play within the co-production cycle of wearable robotic exoskeletons. The user groups that will be analyzed are from the medical, military, and labor fields. A socio-philosophical perspective will be used to analyze literature where wearable robotic exoskeletons were designed to meet the needs of specific groups. The co-production cycle of wearable robotic exoskeleton technology is greatly influenced by the needs of user groups. The industry is built on the needs of those who require the technology.

In the case of more recent wearable robotic exoskeleton designs, there has been a greater emphasis put on the physical aspects of the mechanism, rather than also taking into account psychological impact.

In order to answer the research question, first, cases of created wearable robotic exoskeletons will be analyzed to determine what factors are taken into account when deciding on the design. Following this, the paper will look into what users may need on a social and ethical level and whether or not these needs are already being addressed. Finally, guidelines and regulations that could potentially limit development with the intent to keep users safe will be assessed. The scope of the paper is limited by the allotted length of the paper. When defining user groups, the paper will focus more on medical exoskeletons than military or labor-based exoskeletons because of the greater amount of research and development that has been conducted on medically used WREs.

Case studies

In reports describing the process and creation of a wearable robotic exoskeleton, they often discuss criteria of success when testing their finished product. Many of the concerns lie with the user's physical needs along with just general functionality. A study was conducted using 191 experts from the wearable robotic exoskeleton field to assess the involvement of user-centered design methods during the development of lower limb wearable robotic exoskeletons and how they are used in each stage of production. It was found that 71% of participants used functional tests and measures, making them the most common, while the least common were pain measures and emotional responses, only used by 28% of respondents (Ármannsdóttir et al., 2020). The two selected exoskeleton studies reflect this data. The two exoskeleton case studies selected for this paper discuss functionality and comfortability in terms of user needs, but fail to discuss the social and ethical needs of the user.

Carry

One case study selected for this report is the *Carry* exoskeleton created for lifting heavy loads. The goal of *Carry* is to "prevent systematic, aerobic, and/or possibly local muscle fatigue that may increase degeneration and pain due to lifting, holding, or carrying" (Nassour et al., 2021). In the past there have been many rigid powered exoskeletons, however users benefit more from passive devices according to the report. For this reason the engineers chose to design a passive exoskeleton. “A passive exoskeleton [uses] elastic materials to store and release energy during lifting works and do not use a power source but use materials, springs, or dampers to store energy and release it when required” (Editorial, 2021). The *Carry* exoskeleton utilizes a soft human-machine interface with a soft pneumatic actuation to create a passive structure. After testing the device with users, it was reported that there were no major discomforts felt, however it was discovered that some ”uncomfortably high forces were felt at the locations of the force transmission triangles” (Nassour et al., 2021). The project is limited by the user’s comfort. Only a certain amount of actuator pressure can be used before the forces become too much for the user’s arm and shoulder. Solutions to distribute forces over a wider body area will be looked into to fix this problem (Nassour et al., 2021). In this case study, the user's physical comfort takes precedent over maximizing force. Both comfort and increased force are beneficial to the user, however, comfort has a larger impact on future variations of the exoskeleton.

CUHK-EXO

A wearable exoskeleton named CUHK-EXO was created with the intent of aiding paralysed patients perform typical daily activities like sitting down, standing up, and walking. During the development of CUHK-EXO, ergonomics, user-friendly interface, safety, and comfort were taken into consideration. The design utilizes a set of crutches for since the mechanism can not achieve all the degrees of freedom that are necessary for comfortable motion assistance. A Human-Machine Interface was created as an app to make information exchange between the wearer, therapist and exoskeleton easier. Clinical trials were conducted with a man with poliomyelitis and results showed that CUHK-EXO was effective in aiding the patient with daily activities. Functionality and comfortability shared equal roles in terms of how this exoskeleton was built. The engineers wanted the exoskeleton to be easy to use for the wearer, thus creating the app, making the whole process of learning more comfortable (Chen et al., 2017).

Comparison

In the design process of both Carry and CUHK-EXO, user input was vital in testing the functionality of the device. They both put an emphasis on the physical comfort of the user as criteria for success. It took precedent over the overall performance of conducting daily activities. However, neither study discusses societal implications or the way in which the device makes the user feel mentally. They do not acknowledge the role that the disability stigma plays in their designs and what they do to combat it. This has to be part of their criteria for success, or users will reject their product, hindering the co-production cycle of the technology.

Current Needs of Users and Their Implications

The way the user feels towards wearable robotic exoskeletons and the way society as a whole views the technology plays a large role in its co-production cycle. Regulations and guidelines developed because of the close interaction between human and robot create specifications for this technology design to follow. Wearable robotic exoskeleton technology has many branches of application, therefore designs have to be tailored to the specifications for each job, but individuals' needs across each branch can be quite similar.

The stigmatization of people with disabilities creates a barrier that engineers must overcome in order for users to accept wearable robotic exoskeletons when they are created for medical applications. For those with physical disabilities, they may require more technology in order to be present in society, but this difference can also be a cause for them to be isolated socially. Some disabilities are severe enough to prevent individuals from participating in society and result in a loss of independence because of limited mobility. When an engineer focuses solely on the goal of providing a user mobility with their design, they may be neglecting the politics that surround the technology and the lasting impacts they could have.

A user may not be wholly comfortable with potentially altering their body in order to use this technology. For biomedical engineers working with people with Duchenne muscular dystrophy (DMD) in the Netherlands, rejection of this technology happens quite often, despite functioning properly, due to reasons like “their social context, resulting in a lack of cosmetic appeal, social restriction or stigma”(Kapeller et al., 2020). Exoskeletons can be very bulky and noticeable, which could garner unwanted attention, making someone feel like an outcast in society. It can make an individual feel more isolated from their able-bodied peers, which would be counterproductive to the goal of allowing the user to be more present in society. The stigma surrounding wearable robotic exoskeletons and disability has a large effect on whether a user is willing or not to actually use the technology. When designing an exoskeleton, engineers must be aware of the stigma and create something that does not add to it using a socio-philosophical perspective (Kapeller et al., 2020).

There is a dichotomy when it comes to wearable exoskeleton technology: the problem of assistance and acceptance. Disabled individuals may require the assistance of technology in order to participate in their communities, but still do not want to be “fixed” by the technology or that using the technology will contribute to the stigma surrounding disabilities (Kapeller et al., 2020). Engineers have to take into account both aspects of this problem to develop a satisfactory product. Engineers have a tendency to focus on the technical goals that result in a structurally functioning device and pose disability as a problem that must be fixed, patronizing disabled individuals to change their bodies so they fit societal norms. There have been a great deal of new developments in the field, but a significantly smaller number of them have actually pierced the clinical setting. Engineers' more technology-driven approach and the limited interaction between the field with therapists and clinicians likely plays a major role in this issue (Gassert & Dietz, 2018).

During the design process, engineers must be aware of the social concerns related to wearable robotic exoskeleton technology. These concerns could have a lasting personal and psychological impact on the individuals using the devices and their families (Greenbaum, 2016). Ableness is a prominent social concern. Engineers are limited and how much they can actually do about this issue. There are cultural definitions of “able” and “disabled” that cannot be simply changed overnight. The use of wearable robotic exoskeletons is a product of these definitions and are embedded with the idea of ableism, as they were created to make “disabled” bodies fit the norm (Sadowski, 2014).

The question of whether or not using a robotic exoskeleton is considered enhancement begins to come into play. For those who are born with disabilities, use of an exoskeleton would enhance their body from its typical status quo. Disabled individuals’ mobility would benefit greatly from this technology, but how it is developed is limited by the way people who are born with disabilities are viewed by society. WREs may be developed more with people who became disabled later in life in mind because the technology returns the individual to their status quo, rather than the “enhancement” it gives to those born with a disability (Greenbaum, 2016).

As wearable robotic exoskeleton technology is further developed and integrated into society, the lasting impacts on users must play into the creation of guidelines and regulations. WREs are intimately linked to the user, thus they can alter the user’s self-perception and identity. A wearer could be affected by how well they can use the device or possibly struggle with body image. They could feel as though they are too machine-like or question the ownership of their bodies. These concerns will affect the way exoskeletons are implemented into the lives of users and what regulations should be put on their use (Kapeller et al., 2020). Furthermore, since exoskeletons are created with the purpose of helping with daily activities, it is to be expected that people will use them in public spaces when they go about their day. Because of this, these exoskeletons have to be more "portable, fashionable, and svelte in the future" (Gopura et al., 2011). Engineers will have to find materials and design actuators that are a lot sleeker and lighter for easy transport and cosmetic appeal. The materials used should make the exoskeleton become like a second skin to the user. However, even though this may make the device more comfortable, it also contributes to the idea of dehumanization. The exoskeleton becomes an important part of the person, but then to what point are the machine and human separated from each other?

It is plausible that individuals who use wearable robotic exoskeletons - whether that is in a military, workforce, or medical capacity - will be dehumanized, causing them to be viewed more as a machine than a human. It is especially concerning in military situations. If soldiers are armored with these devices then enemies may fail to view them as human (Greenbaum, 2016). In this case, it is crucial that engineers focus on the needs of users rather than just meeting the technological requirements that deem the device as functional. It has to be acknowledged that the technology could do more harm than good in any of these fields, so what branches grow with these technologies needs to be thought through thoroughly before the industry really begins to grow.

In relation to this, the growing need for the technology may lead to dependencies on WREs which could lead to withdrawal because of how many capabilities the technology can provide. Any number of issues can lead to the loss of the device such as finances or technical malfunctioning. In addition, once the technology is exposed enough to society that exoskeletons are seamlessly incorporated into it, there may come a point where if one doesn't change their body with the tech, they may be viewed as disabled. As progress and distribution of exoskeletons increase, the needs of users will also evolve. People who at this point in time are not considered disabled by definition, could potentially need these mechanisms to fit the new norm of being able-bodied, thus increasing the demand and market for WREs (Sadowski, 2014). This will continue to change the ways in which exoskeletons are needed and how they meet those needs. Instead of creating exoskeletons strictly for mobility needs, they could become a symbol of status and "needed" for cosmetic purposes. This will stray the focus from users who truly need WREs, like people with disabilities, and will become a common item to have like a cell phone.

Interest in wearable robotic exoskeleton technology has increased in demand in part due to the growing elderly population. WREs can allow elderly people to maintain their independence and maintain their quality of life despite aging. Using this technology can reduce the burden on care services. Aging can come with a multitude of medical issues which also need to be factored into WRE designs. Because of some of these issues, the wearer cannot provide the motion trajectory since they cannot perform the required movements (Rupal et al., 2017). This means each exoskeleton has to be designed with individual specifications for each user. In addition, there is the concern that adoption of the technology in elderly populations could be difficult because they tend to be slower to adopt and understand new technology than younger people. Research has to be conducted on older users to understand and optimize older adults' acceptance. There currently is not enough known about older adults' opinions on wearable robotic exoskeletons (Shore et al., 2018).

An exoskeleton can increase sociability on a mental and physical level. The elderly will be able to move better, but there is also that gained sense of independence and autonomy that will make them more willing to interact with others and go about their daily tasks. This leads to a decreased risk of depression and isolation (Shore et al., 2018). As the population that needs wearable robotic exoskeletons grows, WREs designs must grow to be more adaptive. As the elderly continue to age, and hence begin to lose body functionality, the exoskeletons have to adjust to fit the level of assistance required, rather than having to replace the whole exoskeleton everytime the level of need changes (Rupal et al., 2017). Many of the exoskeletons seen today are developed with a specific purpose in mind, like to aid those who have had a stroke or people who have Duchenne muscular dystrophy (DMD), but an exoskeleton should be made to work in multiple different cases.

In order for wearable robotic exoskeleton technology to develop successfully, users have to accept the devices they are being presented. For more devices to be accepted, users have to be present throughout the entire process of development. Users can be involved in multiple steps throughout the design process in order to ensure their individual needs are being met. They can be included with questionnaires, prototype testing, brainstorming, interviews, observation, post release testing, and psychophysical methods (Ármannsdóttir et al., 2020). Furthermore, the integrating of ethical and legal considerations into the design will facilitate the building of trust between the users and engineers, leading to increased acceptance (Kapeller et al., 2021). There is a great amount of human-robot interaction between the user and the WRE since the device is making contact with the user’s skin. There have to be safety regulations put in place to ensure there are no complications with the user.

User involvement can be limited by factors outside of the engineer's capabilities. “Some limitations include lack of patient availability and/or funding, and the possible need to validate a system before permission to test with users is granted" (Ármannsdóttir et al., 2020). There is no standardized method of evaluation because of ethical, financial, or methodological challenges in addition to personal and environmental factors. The intended purpose of the device also plays a role in this. There are so many factors that make the issue complex that it is difficult to create a standardized method of evaluating every wearable robotic exoskeleton. This results in inadequate data on user input in devices. (Ármannsdóttir et al., 2020).

Conclusion

It can be argued WREs are an act of ableism, and their co-production cycle is influenced by their potential overarching affect on society rather than what individual users need. Wearable robotic exoskeletons are created as a means to fit disabled bodies into a very ableist society, rather than changing the environment so that everyone has access to it. WREs enforce the idea that there is a "normal" body, and that people with disabilities must be changed in order to fit this ideal (Sadowski, 2014). Disabled people only need these devices because they will be separated from society otherwise. This argument has merit, but WREs seem to be a best case scenario in this situation. People with disabilities are being forced to fit the norms of society', but engineers can only change so much of the environment because of the way society has developed to isolate disabled people. Creating WREs meets the requirements set by society, which benefits users and allows them to be present in their communities.

Comfortability is a large factor that limits how the technology is built. Comfortability refers to not only the physical comfort of the user, but if they mentally feel comfortable with the way the device changes their body and how people may view them. Both these aspects affect the amount of force the exoskeleton can use, materials that can be used, and the cosmetic appeal of the design. This also affects the way engineers can go about designing the WREs from the beginning. Engineers have to rethink how they conduct testing, introduce the technology to the user, and then introduce the technology to society. They have to be aware of how they pose their ideas, especially in the context of disability, where the problem of ableism becomes an issue.

The more the public becomes interested in WREs, the more adaptable the design has to be. If they need to fit the needs of a variety of people it's easier to make them multi-purpose from the start so they can have many uses without having to create so many different designs. For the wearable robotic exoskeleton's co-production cycle, there will be a lot of change in progress due to the user's needs in the future. The close interaction between human and robot will be the driving force behind the cycle. Through the exploration of my STS thesis, I have learned about the different aspects of users' needs that must be met for a wearable robotic exoskeleton design to be successful. I have to be conscious of the preconceived notions surrounding disability and be aware of how my designs could contribute to the stigmatization. During the design process of the technology, the user should be as involved as possible in each step.

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